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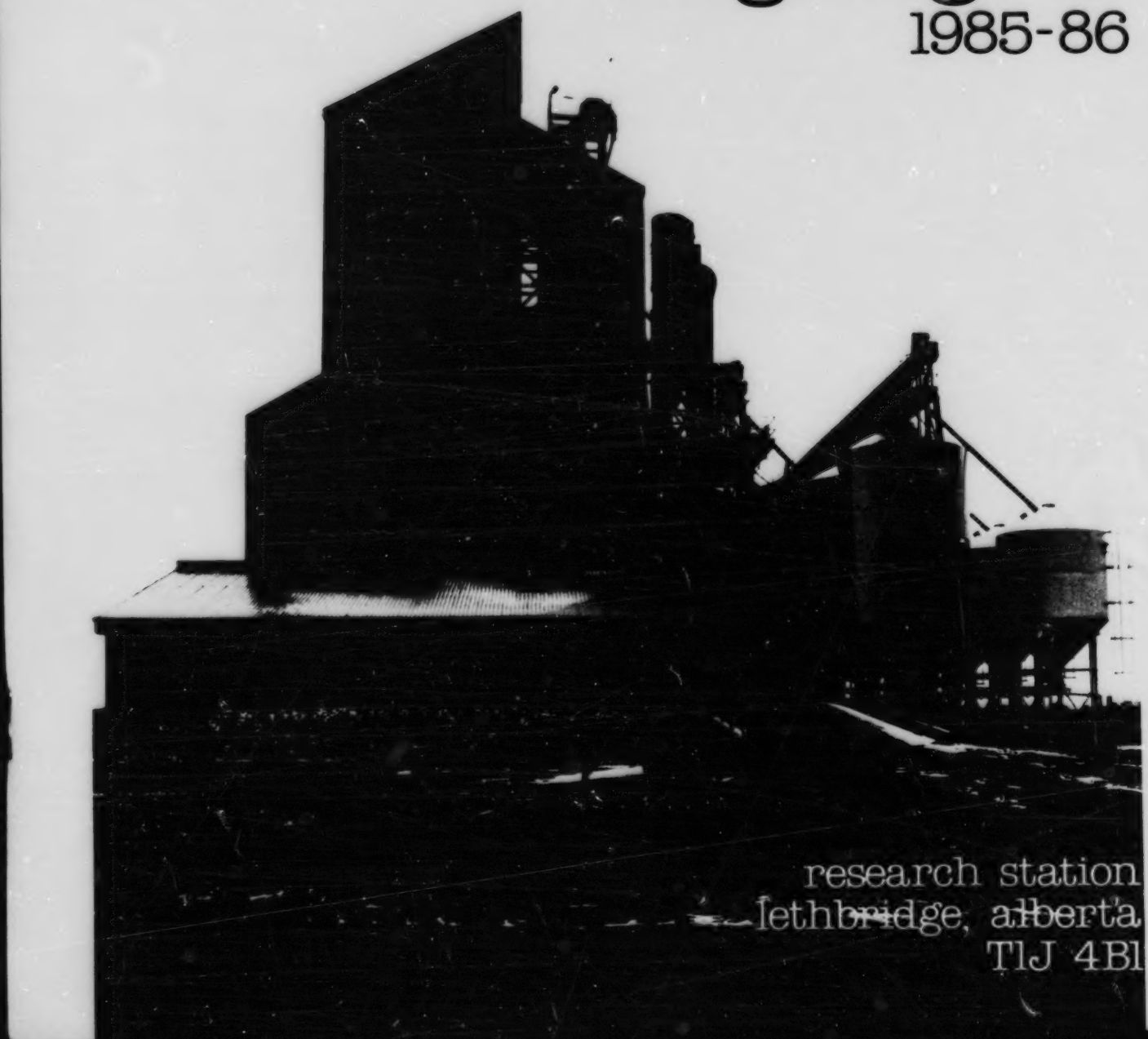

research station
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Front cover: Rations for livestock research are prepared in the computerized Feedmill opened in 1986.
(Photo: J. Kolpak)

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F. R. Harper, Ph.D., *Retired 31 December 1986*

W. O. Haufe, Ph.D., *Retired 31 January 1986*

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introduction

D. G. Dorrell
Director

This issue of Research Highlights contains summaries of some of the research activities conducted at the Lethbridge Research Station during 1985 and 1986.

The year 1986 was highlighted by an open house and field day to celebrate the Centennial of the Research Branch and the 80th Anniversary of the Research Station. Two major new facilities--a research feedmill and a controlled environment livestock facility--were completed, thereby enhancing our ability to conduct specialized livestock research.

The Lethbridge Research Station conducts research at its 500-ha dryland and irrigated site at Lethbridge, a 17,000-ha beef cattle station at Onefour, a 400-ha ranch in the foothills near Stavely, and a 130-ha irrigation farm at Vauxhall. Fundamental and applied research focuses on plant breeding, the control of plant diseases and insect pests, soil fertility, tillage, water use, livestock improvement and nutrition, and the control of livestock pests.

During 1985 and 1986, several staff changes occurred at the Station. Among these, Dr. E. E. Swierstra, Assistant Director, was promoted to Director of the Brandon Research Station; he was replaced by Dr. D. L. Struble, who became Acting Assistant Director in addition to his responsibilities as Head, Crop Entomology Section. Several key individuals, Mr. S. B. Arnason, Head of Administration; Dr. F. R. Harper, Head, Plant Pathology Section; Dr. W. O. Haufe, Head, Animal Parasitology Section, and Dr. D. B. Wilson, Head, Plant Science Section, retired after long and distinguished careers at Lethbridge. Dr. P. J. Scholl, USDA scientist on the Canada-USA grub project completed his 4-year secondment and returned to Kerrville, Texas.

Several appointments were made: Dr. C. W. Lindwall replaced Dr. D. C. MacKay as Head, Soil Science Section; Mr. J. A. Shemanchuk was named Acting Head, Animal Parasitology Section; Mr. B. D. Clark became Acting Head, Administration Section; Mrs. M. M. Tarnava joined the staff as Administrative Officer - Personnel, and Mr. D. W. Pang became the new Computer System Manager. The following research scientists joined our staff: Dr. P. Bergen, weed control; Dr. M. F. Hynes, microbial genetics, Dr. L. M. Rode, animal nutrition, Dr. R. S. Sadasivaiah, spring wheat breeding, and Dr. J. Yeung, pesticide metabolism.

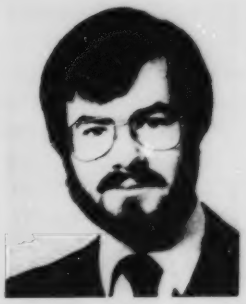
Our scientists hosted visiting scientists and foreign delegations; participated on graduate students' thesis committees, international secondments, and exchanges; and served on numerous provincial, national, and international committees. Several of our clients participated directly in our research activities; Farming for the Future of Alberta Agriculture partially funded 11 projects, the Western Grains Research Foundation funded four projects, and new collaborative research was initiated with several companies.

We hope that you will find our Research Highlights informative. Please contact any of the scientists or our Technical Information Officer for more details and more information on other aspects of our research.

new research initiative

GENETIC MANIPULATION OF NITROGEN-FIXING BACTERIA

M. F. Hynes



Biological nitrogen fixation is of great importance to agriculture. It is carried out by free-living micro-organisms and micro-organisms in symbiotic association with higher plants. New projects initiated at the Lethbridge Research Station will investigate the potential for improvement of biological nitrogen fixation by genetic manipulation of the bacteria that carry out this process. Work will be carried out with Rhizobium-legume symbioses and with nitrogen-fixing bacteria associated with wheat.

Studies on Rhizobium will focus on the genetics of competition for nodulation. Competition represents the most serious obstacle to the use of rhizobial inoculants to enhance nitrogen fixation in the field. This is because native Rhizobium strains in the soil, which often fix nitrogen very poorly, frequently out-compete the introduced inoculant, even when the latter is applied at a rate of a billion bacteria per seed. The result is that the vast majority of nodules formed on a legume crop can be formed by Rhizobium strains that fix nitrogen poorly or not at all, rather than by the desired strains used as inoculants. New research will focus on identifying genetic factors that contribute to competitive ability and to favorable strain-cultivar interactions, and introducing these characteristics into rhizobial strains by genetic manipulation with the aim of producing better quality, more competitive inoculants.

Previous research at Lethbridge has shown that bacteria found in the rhizosphere of some wheat cultivars are capable of fixing significant amounts of atmospheric nitrogen. However, the amounts of nitrogen fixed are not sufficient to meet the requirements of the wheat plants. New research using various techniques of genetic engineering will determine the potential for increasing the amount of nitrogen fixed by these bacteria. Some factors that will be investigated include tolerance of these systems to the presence of fixed nitrogen, the influence of host plant cultivar on the amount of nitrogen fixed, and regulation of nitrogen fixation.

background and outlook

THE 1986 WEATHER

W. C. Anderson

Although June of 1985 was a record month, with the lowest precipitation in 85 years, things looked brighter in 1986. Average precipitation during the spring and summer of 1986 brought an abrupt end to two consecutive years of drought conditions in southern Alberta. Record yields were reported in many areas.

However, above-average precipitation during September interfered with harvesting operations and resulted in grain quality deterioration. In August, the Alberta Wheat Pool estimated that over 75% of the 1986 hard red spring wheat crop in Alberta would be Canada No. 1 and 2 grades. After the September rains, less than 30% of the crop met these grades and over 70% was graded Canada No. 3 and feed grain.

A warm spring and summer accounted for the increased annual mean temperature (7°C, up 36% from 5.0°C, the long-term average). The above-average temperatures for the months from March to August provided ideal conditions for a good crop year. The cool September (mean temperature of 9°C) (Table 1) brought a quick end to the season. The number of frost-free days (115) was slightly below average (117) but crop days (164) were well above average (140) (Table 2) and were the highest since 1980.

Annual precipitation for 1986 was only slightly above average (408 mm in 1986 compared with 404 mm). September was the wettest month of the year with 97 mm precipitation. This was not as much as in September 1984 (108 mm) but did exceed September 1985 (87 mm). The excess water was of benefit to forage crops and pastures. As expected, dugouts were filled.

Problems of harvesting in October resulted in late winter wheat seeding. However, germination was good in stubble as well as fallow.

The 106 cm total snowfall for 1986 was lower than the 85-year average (141 cm). Snowfall was a minor component of the total precipitation and accounted for only 16% of the total. This is a small contribution to overwinter moisture and is typical of the dry winters in southern Alberta.

The wind for September (12 km/hr) was 31% below the long-term average and the evaporation (98 mm) for the same month was 35% below the 19-year average. The yearly evaporation total (1346 mm) was slightly above the long-term average of 1330 mm.

The sunshine record indicates that the 114 hours for September 1985 were the least amount of sunshine in 78 years. The 1986 September total of 119 hours is a close second. The long-term average for this month is 208 hours.

The outlook for 1987 is an optimistic one.

Table 1. Meteorological data at the Agriculture Canada Research Station, Lethbridge, Alberta - 1986.

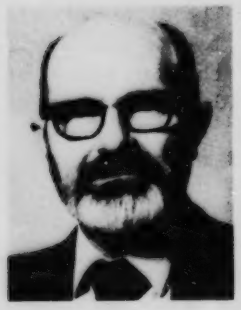
	Temperature (C°)						Sunshine (hours)		Wind (km/hr)					Evaporation (mm)		Precipitation (mm)	
	Highest		Lowest		Mean				Mean velocity		Maximum hourly velocity						
	1986	85-yr avg	1986	85-yr avg	1986	85-yr avg	1986	79-yr avg	1986	66-yr avg	1986	Direction	Date	1986	19-yr avg	1986	85-yr avg
Jan	14	11	-18	-31	1	-9	89	98	24	21	82	W,WSW	8,11			6	19
Feb	18	13	-39	-29	-9	-7	113	122	14	21	89	WSW	24			21	18
Mar	21	17	-11	-24	5	-2	148	162	21	20	87	W	27			25	24
Apr	23	24	-12	-11	6	5	245	207	23	21	59	WSW,W	19,28	178	144	18	32
May	34	28	-3	-4	12	11	244	257	17	20	70	W	13	207	204	71	55
June	34	30	5	2	17	15	318	280	15	18	59	W	11	272	242	52	72
July	30	33	5	5	17	18	319	342	14	16	69	SW	17	241	261	16	41
Aug	33	33	2	3	18	17	309	301	10	15	59	NW	5	242	222	19	41
Sept	26	29	-1	-3	9	12	119	208	12	17	54	W	10	98	147	97	42
Oct	24	25	-8	-10	9	7	208	170	14	21	69	NNE	9	108	110	39	22
Nov	14	17	-27	-22	-3	-1	109	113	19	21	76	W	15			40	19
Dec	12	12	-22	-29	0	-6	131	94	21	22	74	W	1			4	19
Total							2352	2354						1346	1330	408	404
Mean					7	5			17	19							

Table 2. Frost records for 1986 and 85-year averages at Lethbridge Research Station.

		1986	Average
Last frost (spring)	Date	May 15	May 21 (12)[1]
	Temp.	0.0°C	
First frost (fall)	Date	Sept. 7	Sept. 15 (11)
	Temp.	-1.0°C	
No. of frost-free days		115	117 (17)
Last killing frost (spring)	Date	May 1	May 7 (11)
	Temp.	-2.5°C	
First killing frost (fall)	Date	Oct. 11	Sept. 25 (10)
	Temp.	-5.5°C	
No. of crop days		164	140 (16)

[1]Values in parentheses are standard errors (±) in days.

PLANT DISEASES - 1985-86



F. R. Harper

The drought that prevailed in southern Alberta throughout the growing season of 1985 kept losses from crop diseases to a minimum. In contrast, many diseases were prevalent under the cool moister weather of the 1986 growing season. The most notable of these was stripe rust, which caused serious losses to late-maturing soft white spring wheat and injury to cereals and other crops by high soil surface temperatures in late May.

Cereal Diseases

In 1984 a severe summer drought delayed sowing of winter wheat. In consequence, many fields did not develop maximum winterhardiness and low temperature injury was common throughout Alberta. Abundant fall moisture in 1985 and early sowing of most of the winter wheat crop assured that even the coldest November on record had little adverse effect on survival. Adequate snow cover before the cold weather provided excellent insulation for the developing wheat seedlings and no winter injury occurred.

Cottony snow mold, an important disease of overwintering cereals in areas with abundant and persistent snowcover, caused damage only in the Peace River District in 1985. In 1986 the disease was found in central Alberta and caused greater damage than in 1985 in northern Alberta.

Stripe rust, a serious wheat disease in the Pacific Northwest of the United States, continues to causes losses to irrigated soft white wheat in southern Alberta. In 1985 the disease was not found until late July. Even so, it developed rapidly in late-maturing fields in the Brooks and Vauxhall areas and reduced yields in a few. The rust spread to newly emerged winter wheat seedlings in the fall of 1985 and a mild winter allowed the fungus to survive and form spores on the overwintered leaves to provide unusually early inoculum for spread of the diseases in the spring of 1986. Fortunately, the moderate resistance of Norstar winter wheat to stripe rust and dry weather in May and June slowed development and spread to susceptible soft white wheat fields. This allowed early sown fields to escape serious damage. However, cool and moist conditions in late July and August promoted rapid development of stripe rust in the late-maturing fields, resulting in serious losses in the susceptible cultivar Fielder. The recently released stripe rust-resistant cultivar Owens was not damaged and application of the fungicide Bayleton just when the spikes were emerging effectively controlled the rust on Fielder.

The unusually moist August and September of 1985 and 1986 favored development of kernel black point, a disease that lowers the grade of affected grain. Surveys of soft white wheat indicated 9.8% of the grain in 1985 and 15% in 1986 was damaged by black point.

Scald and net blotch, the two most important barley leaf diseases, were essentially absent from barley fields in southern Alberta in 1985 and 1986. In contrast, these diseases were common from Calgary north where rainfall was more abundant. Losses from scald in 1986 were particularly severe in the Calgary and Olds areas. Tan spot was found more often on the leaves of soft white spring wheat in 1986 than in 1985.

Two consecutive years that were too dry for ergot to develop appear to have almost eliminated the disease from grains and grasses in southern Alberta. Even though several periods favorable for infection occurred in 1986, no ergot was found in grains or grasses in southern Alberta.

Take-all, a disease that has recently become a problem in irrigated wheat, caused more serious damage in 1986 than in 1985. The recent identification of improved resistance to take-all and common root rot in genetic material transferred from one of the grasses into wheat looks promising for improved control of these diseases in the future.

Severe yellowing of the second and part of the third leaves of most tillers of barley was widespread in southern Alberta in early June 1986. Damage, which was very uniform from field to field, was attributed to heat injury resulting from several days of clear, hot weather that raised the soil surface to near-lethal temperatures.

Diseases of Forage Crops

Verticillium wilt continues to limit the life of irrigated alfalfa stands in southern Alberta. By 1985 the disease had been found in all irrigation districts in southern Alberta and was well-established in the Lethbridge and Taber areas. In 1985 the disease was found for the first time in Alberta in a dryland alfalfa field. Barrier, a new alfalfa cultivar which is resistant to both verticillium wilt and bacterial wilt, continues to yield well in field tests at Lethbridge and Creston.

Oilseed Crop Diseases

Sclerotinia stem rot was not a problem in canola grown on dryland in 1985 or 1986. In contrast, the disease was present in 73 and 84% of the fields of irrigated canola surveyed in southern Alberta in 1985 and 1986. Head rot, also caused by Sclerotinia, was a major problem in commercial sunflower fields grown at Bow Island.

The virulent strain of the black leg fungus that has caused serious losses to canola in Saskatchewan was found for the first time in commercial canola fields in Alberta in 1985. The outbreak involved several fields in east-central Alberta near Vegreville. Surveys in 1985 and 1986 failed to find this strain of the black leg fungus in southern Alberta.

Diseases of Other Field Crops

Surveys of southern Alberta white bean fields in 1985 and 1986 found all fields to be damaged by sclerotinia white mold. Control of this disease by aerially applied fungicides has become an established practice by most bean growers in the Bow Island area in recent years.

Verticillium wilt, blackleg and rhizoctonia stem canker were the diseases found most frequently in commercial potato fields in 1985 and 1986. Verticillium wilt caused the most damage in 1985 whereas in 1986 blackleg was the most important. Early blight, a leaf disease that is sometimes widespread on potatoes, was seldom encountered either year.

INSECT PESTS OF FIELD CROPS - 1986

D. L. Struble

This report on insects affecting field crops in Alberta in 1986 is based on information supplied by entomologists from the Crop Entomology Section of the Lethbridge Research Station and by provincial agencies.

Southern Alberta experienced a severe infestation of grasshoppers again this year. In 1985 about 700,000 ha were sprayed for grasshopper control and about 570,000 ha were treated in 1986. The abundance of grasshoppers in Alberta is expected to decrease slightly in 1987 and about 500,000 ha are expected to require treatment. This estimate is based on the adult and egg survey (see Johnson, p. 8), but the final result will depend in part on the spring weather and crop conditions.

Pale western cutworm infested about 28,000 ha of cereal crops in Alberta this year, a decline of 75% from 1985. Infestations were less widespread and generally less severe than expected because crop stands, particularly winter wheat, were in good condition and could withstand moderate numbers of cutworms. Sex-attractant trap monitoring of pale western cutworm moths at 81 sites within a 13,000 km^2 area of southern Alberta reliably forecasted the areas where infestations were likely to occur. Moth catches this fall showed that the population had declined by only 25% from 1985, and is still sufficiently high to cause a severe infestation in the spring of 1987 if conditions are dry. The abundance of army cutworm moths increased this fall and this species may be a problem again if this trend continues. Monitoring for five other species of cutworms and bertha armyworm showed that their populations were all relatively low and are not expected to be a problem in 1987.

Sex-attractant trap monitoring of European corn borer showed that the population from Medicine Hat to Lethbridge was the same as in 1985. The greatest numbers of moths were captured in the Medicine Hat to Bow Island area, with very few from Purple Springs to Cranford and none at Lethbridge. The infestation at Medicine Hat was equivalent to that in Manitoba in 1984; however, stalk breakage in the irrigated silage and grain corn was less than 3% in Alberta. Fresh market sweet corn was treated for larval control in the Medicine Hat to Bow Island area and this practice is expected to continue. European corn borer is not expected to be a problem in the Taber area in 1987.

The brown wheat mite was reported on several fields of winter wheat near Milk River and Warner in 1985 and on fields of recropped barley near Nobleford, Welling and Cardston in 1986. It has been associated with a general yellowing of the plants. This species has been a problem in Montana since 1983 where it was recently found to be a vector of barley yellows mosaic virus. The mite can be controlled with Lorsban, which has temporary registration. Crop rotation and heavy rains in May and June will reduce the infestations.

An aphid called the greenbug infested late crops, mainly south of Highway 3 from the foothills to Saskatchewan. There were about 1.2 million ha infested and an estimated 100,000 ha were treated for aphid control. Durum wheat and barley appeared to be the most severely infested. The greenbug is a serious pest of cereal grains and sorghum in Texas, but populations that warranted control have never previously developed in Alberta. The aphids appear to have been carried into this area by a weather system, so we do not expect this species to be a problem next year.

A green grass bug was abundant during May and early June on barley and soft white spring wheat throughout the irrigated area between Lethbridge and Taber. Damage consisted of extensive white spotting and, in severe cases, splotching of the leaf blades. A few fields of barley became whitish in appearance and were sprayed with insecticide; the crops recovered quickly.

This pest was most prevalent in fields that had been seeded to cereals for several years in succession and it could become a problem in irrigated fields that are continuously cropped with cereals.

The incidence of wheat stem sawfly increased this year and in some areas considerable damage occurred when susceptible varieties of spring wheat were left for straight combining. There were a few reports of damage to winter wheat; in Montana, winter wheat has been quite severely damaged in some areas in recent years.

Wheat head armyworm was reported in several fields of winter wheat in the Warner area. The larvae feed on the developing kernels, and the damage is often undetected.

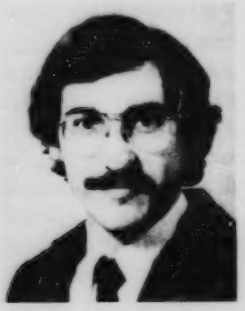
White grubs destroyed about 6 ha of barley near Del Bonita in a field of freshly broken grass.

The major pests of canola in southern Alberta were flea beetles, grasshoppers, pale western cutworm, cabbage aphid and lygus bugs. The populations of bertha armyworm and diamondback moth were very low. There were a few reports of potato aphid on flax.

Alfalfa weevil were abundant again this year and about 90% of the seed alfalfa fields in southern Alberta were treated for their control.

THE GRASSHOPPER OUTBREAK IN ALBERTA, 1984-87

D. L. Johnson



Grasshopper abundance in Alberta will continue to decline in 1987, although the drop in numbers is not expected to be as great as the reduction from 1985 to 1986. The decline predicted in the 1986 Alberta grasshopper forecast released in December, 1985 was mainly due to poor conditions during the main part of the breeding season (late July through early September).

This year, moderately warm and dry August weather allowed considerably more egg-laying than in August, 1985. Only 19 mm of precipitation were recorded at Lethbridge in August of 1986, compared with over 88 mm the previous August. September weather was cool and moist during the past 3 years, precluding much late-season egg-laying. The eggs that were laid in August, 1986 had adequate soil moisture for embryonic growth.

The Alberta grasshopper forecast map is produced at the Lethbridge Research Station and is based on data collected by Agriculture Service Board Fieldmen and by Research Station staff at over 1700 locations in 1986. Consideration of the effects of weather on breeding success, and surveys of the number of egg pods per unit area, have allowed an improvement in forecast accuracy. Results from spring egg surveys were incorporated into an updated forecast map issued in March, 1987.

The forecast for 1987 indicates that the area infested has dropped slightly, but that the geographical pattern has broken up, resulting in greater variability in abundance between nearby sites (see 1986 map).

The estimates of the area infested at the end of the 1986 summer (Table 1) serve as the best estimates for the areas that may have spring crop damage from grasshoppers in May and June, 1987. As has been the case since the 1984 drought, the grasshopper problem will be concentrated in the southern part of the province (Table 2). In

1987, 6 million ha are expected to have potential problems, with 2 million ha in the severe to very severe class. Typically, one-fourth to one-third of this area is treated with insecticide, so 500,000 ha is a reasonable expectation for the area requiring treatment this year. This represents only a slight decrease from 1986. The estimate is approximate, and the final value depends in part on spring weather and crop value.

Table 1. The area (km^2) of agricultural land in Alberta infested with grasshoppers during their breeding season.

	Severity classification from the grasshopper survey				
Year	Very light	Light	Moderate	Severe	Very severe
1981	68,950	14,480	10,670	3,310	930
1982	72,230	22,000	23,390	4,530	1,080
1983	54,540	39,540	33,090	3,860	740
1984	76,890	41,380	25,060	7,920	7,330
1985	61,110	46,400	44,530	25,540	11,590
1986	60,370	35,994	40,919	15,358	3,991

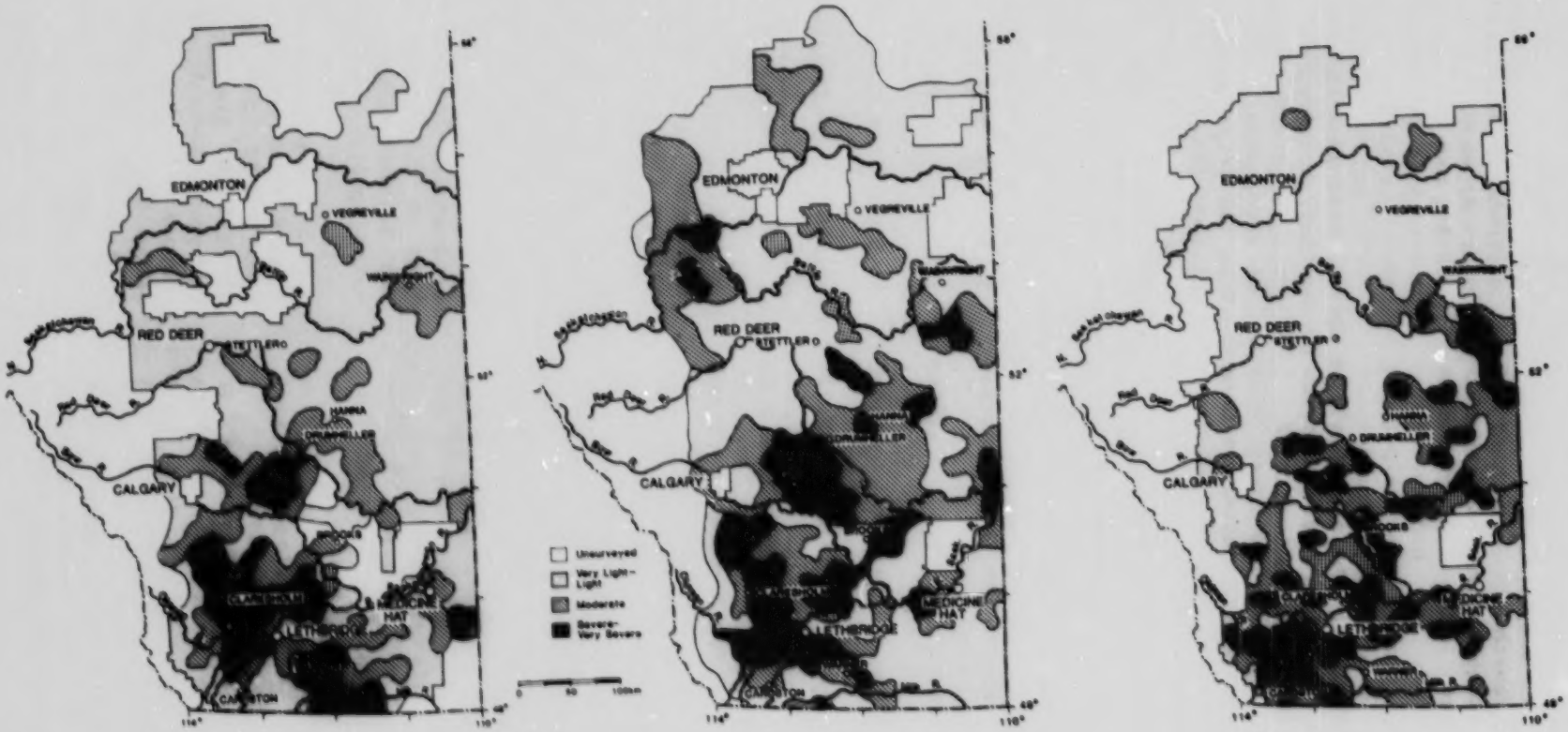
1 km^2 = 100 ha; 1 ha = 2.47 acres

Table 2. Area in each category in the 1987 Alberta forecast.

	Central (N of 52°)[1]	South (S of 52°)
Very light	39,610 72%	20,760 20%
Light	7,198 13%	28,796 28%
Moderate	6,418 12%	34,501 34%
Severe	1,449 3%	13,909 14%
Very severe	0	3,991 4%

[1]52°N latitude marks the northern limit of the mixed grass ecoregion.

Adult grasshopper population density in Alberta.



cattle and sheep

VOLUNTARY INTAKE OF DIGESTIBLE ENERGY BY CATTLE

R. Hironaka and G. C. Kozub

Both the form of hay and the hay to concentrate ratio in diets for cattle must be considered when predicting digestible energy intake (DEI). When long hay formed >60% of the diet, DEI and rate of gain declined. The DEI was not influenced by the level of cubed hay in the diet. For both long and cubed hay, average daily gain increased as the proportion of grain in the diet increased.

The digestible energy intake (DEI) per unit of metabolic body weight ($W^{0.75}$) is a major factor influencing the rate of gain and the feed efficiency of beef cattle. The digestible energy (DE) content of a diet may be estimated from tables of feed composition. However, estimates of DEI are less well defined. With the development of computer programs to formulate diets to maximize profits, it is important to know DEI in order to estimate the efficiency of gain on different diets. It is recognized that both DE concentration and the physical form of the feed influence consumption and thus DEI. However, the interacting influence of these factors is not quantitatively defined. In an experiment at Lethbridge, long (baled) hay and cubed hay were fed with a steam-rolled barley-based diet in five ratios to 10 groups of steers to determine the effect of DE concentration and physical form of the diet on DEI.

The form of hay did affect DEI per $W^{0.75}$. When the concentrate made up 23% of the diet, DEI/$W^{0.75}$ was greater in steers fed the cubed hay than in those fed the long hay diet. As the concentrate was increased from 23 to 41%, DEI/$W^{0.75}$ increased on the long hay diet but decreased on the cubed hay diet. As the concentrate in the diets was further increased to 51 and 60%, the DEI/$W^{0.75}$ remained at the same level seen at 41% concentrate on the long hay diet but increased markedly in steers fed the cubed hay diet (Table 1). With diets containing 23, 32, and 41% concentrate, there was a greater increase in DEI/$W^{0.75}$ per day for each unit increase in DE concentration in the long hay diets than in the cubed hay diets, which reflected the greater fill effect of the long hay.

On the long hay diet, maximum feed intake per day occurred at a hay to concentrate ratio of 59:41, which has a DE concentration of about 2.77 Mcal/kg. With cubed hay diets, feed intake declined as the concentrate portion of the diet increased. The difference in response on the diets with two hay types is attributed to feed intake controlled by rumen capacity in the long hay diets and by a metabolite of digestion in the cubed hay diets. The concurrent increase in DEI/$W^{0.75}$ and concentration of DE in the diet at low levels of concentrate in the long hay diets, and the plateau that was reached when the concentrate formed 51% of the diet, suggest that control of feed intake shifted from rumen capacity to metabolites of digestion between 41 and 51% concentrate in the diet or when the diet contained between 2.77 and 2.92 Mcal/kg.

The average daily gain increased as the level of concentrate in the diet increased for both the long and cubed hay diets. Feed to gain ratio declined as level of concentrate increased for both diets, but DE per unit gain was similar for long hay diets containing 23-51% concentrate. DE per unit gain declined when concentrate was increased to 60%. With cubed hay diets, the DE per unit gain was similar for diets with 23 and 32% concentrate, then declined and was similar for diets with 41-60% concentrate (Table 1). The point at which the efficiency of DE utilization for gain changed was different for long and cubed hay diets.

Steers fed long hay diets had higher dressing percentage, heavier carcasses, and thicker backfat than those fed cubed hay diets (Table 2). Ribeye area was similar for steers fed long and cubed hay but the marbling score was lower

(more fat) for steers fed long hay. There was an increase in the carcass grade score (increased backfat) as the proportion of concentrate in the diet increased, but the average grade score was similar for steers fed on long and cubed hay.

Table 1. Effect of form of hay and percent hay in the diet on feed intake, rate of gain, and feed efficiency.

Form of hay	Hay:Conc.	Feed/day (kg)	DEI/$W^{0.75}$/day (Mcal)	ADG (kg)	Feed:Gain (kg)	DE/gain (Mcal)
Long	77:23	8.12	0.26	0.81	10.1	26.0
Long	68:32	7.93	0.27	0.81	9.8	26.8
Long	59:41	8.42	0.29	0.90	9.4	26.0
Long	49:51	8.00	0.29	0.88	9.2	27.0
Long	40:60	7.74	0.29	1.00	7.8	23.7
Cubed	77:23	8.57	0.28	0.77	11.4	29.6
Cubed	68:32	8.00	0.27	0.76	10.7	29.4
Cubed	59:41	7.89	0.27	0.85	9.4	26.0
Cubed	49:51	7.56	0.28	0.84	9.1	27.0
Cubed	40:60	7.60	0.30	0.93	8.3	26.0
P		<0.01	<0.01	<0.01	<0.01	<0.01

P=Probability that differences are due to chance.

Table 2. Effect of form and level of hay in diet on final weight, days on test and carcass measurements.

			Carcass				
Hay:Conc.	Final wt (kg)	Days on test	Weight (kg)	Dressing (%)	Backfat (cm)	Ribeye (cm^2)	Grade
77:23	473	326	261	55.7	1.35	66	A1.44
68:32	474	323	268	57.3	1.53	68	A1.76
59:41	476	296	272	57.9	1.61	66	A1.80
49:51	475	303	272	58.3	1.67	66	A2.00
40:60	478	271	272	57.2	1.82	66	A2.13
Form of hay							
Long	477	296	273	57.8	1.68	66	A1.93
Cubed	474	312	265	56.8	1.51	66	A1.72
P	>0.05	<0.01	<0.01	<0.01	<0.01	>0.05	>0.05

P=Probability that differences are due to chance.

A COMPUTER MODEL FOR MAXIMIZING PROFITS IN DAIRY PRODUCTION

R. Hironaka and K. K. Klein

A linear programming optimization model for dairy cattle was constructed using experimental data from a feeding trial and from literature values. The model selects a feeding program that maximizes profits per lactation. With slight modifications, the model could be used to determine the most profitable feeding program for component-priced milk.

The amount of concentrate consumed by cows is highly variable and has a marked influence on milk production. High-producing cows are often fed a higher concentrate allowance per kilogram of milk produced than are low-producing cows. However, milk production follows the law of diminishing returns, rising sharply with initial increase in feed intake, then rising at a slower rate with each subsequent increment of increase in feed intake. The most profitable level of concentrate feeding is when the increment of milk revenue from the last unit of concentrate fed is equal to the additional cost of feeding that last unit of concentrate.

The computer model formulates diets to meet specified nutrient requirements, and selects the most profitable rate of feeding. The model includes specific requirements, based on literature values, for digestible energy (DE), protein, calcium, phosphorus, the calcium-to-phosphorus ratio, and vitamin A for each of 10 feeding programs and for each of five 8-week periods during a lactation. The amount of feed is adjusted with the amount of milk produced and the program adjusts the composition of the diet to meet changes in nutrient requirements with different amounts of feed. Ranges in nutrient requirements are given to take advantage of lower feed prices even though some nutrients are supplied at levels above the minimum requirement. The model assumes a similar performance from dairy cows on diets that meet specified nutrient standards, but differ in ingredient composition.

The model was tested with feed and milk prices over 4 years in southern Alberta. Cash and labor costs were held constant over the 4 years and for different levels of feeding. Since the alfalfa intake figures in the model are those obtained from experimental feeding data, they should represent the consumption of producer's cows fed to appetite. The model did not consider non-cash costs, or the costs or revenue of dry cows and young cattle that were not producing milk. Optimal solutions varied with the prices of feeds and milk, and although changes in prices changed the profitability of the dairy operation (Table 1), they did not alter the most profitable level of concentrate to feed.

Composition of the optimal diet, including composition of the concentrate diet and the hay-to-concentrate ratio, also varied substantially among the periods of lactation (Table 2). Production differences between low- and high-producing cows were small; therefore, the daily feed requirements presented in Table 2 are the average for low- and high-producing cows.

The model is currently limited to a maximum concentrate feeding level of 0.35 kg per kg milk produced because this was the maximum level used in the feeding trial that was used as a basis for constructing the model. (Dairy cows were fed 0.15, 0.20, 0.25, 0.30, and 0.35 kg concentrate per kg milk produced, plus alfalfa hay to appetite.) Milk production of many cows is higher than that observed in the feeding experiment, and in these cases, the relationship between feed intake and milk production may differ from that in the present model. Data from such cows can be added to the model to determine their optimal feeding programs.

Table 1. Feed intake of dairy cows, costs, and net returns with different price series.

	Price series (year)			
	1	2	3	4
Hay consumption (kg/cow/day)	15.27	15.27	15.26	14.37
Concentrate consumption (kg/cow/day)	7.23	7.23	7.23	7.23
Average feed cost ($/tonne)	65.58	61.01	74.79	106.49
Feed cost/cow/day ($)	1.48	1.38	1.69	2.30
Net return/cow/day ($)[1]	1.96	2.29	2.64	2.24

[1]Price of milk was only partially determined by feed cost.

Table 2. Average feed requirements (kg/day) by feeding periods in year 4.

	Feeding period				
	1	2	3	4	5
Alfalfa hay	11.93	14.51	14.70	15.16	15.56
Barley	8.46	7.51	6.21	5.71	4.23
Canola meal	1.62	1.07	0.77	0.54	0.24
Vitamin A	0.011	0.010	0.009	0.008	0.008
Salt	0.056	0.048	0.039	0.032	0.025

The model formulates diets to maximize profits, and includes formulations for each of the five 8-week periods in the lactation. In practice, however, producers may not accept more than two diets because of problems in handling multiple diets. The model permits formulation of one or two concentrate diets so that the feeding operation can be simplified, but some of the nutrients will be supplied at levels above the requirements and the cost will be higher than the ideal formulation. This model may be used to compare the net profits with idealized and simplified formulations, and to make a decision on the number of concentrate diets to be used, based on convenience and maximum profit. We expect to adapt the model for use on a microcomputer by producers.

ADHESION OF MIXED POPULATIONS OF RUMINAL MICROORGANISMS ENHANCES DIGESTION OF STRAW IN RUMINANTS*

K.-J. Cheng, H. Kudo, and J. W. Costerton[1]

A study of the association of bacteria with straw in the rumen showed that adhesion of cellulolytic bacteria to straw was a pre-condition for cellulose digestion, that chemical agents promoted adhesion, and that associations of mixed populations of cellulolytic and non-cellulolytic bacteria are necessary for maximum digestion of straw.

Straw is an abundant byproduct of the grain industry and its basic cellulosic structure makes it a potential feed for ruminants. Chemical treatments have been developed that increase the digestion of straw by 10-15% in the rumen and nutrient supplementation has brought chemically treated straw to the point where it is a marginally useful feed.

Because the digestion of straw is largely a function of digestion of cellulose by native rumen microorganisms, we have studied the adhesion of these cellulolytic microorganisms to the surface of straw particles and the effects of these microbes on digestion of the cellulose. We found that cells of the three main species of cellulolytic bacteria of the rumen must actually adhere to the cellulose to be able to digest it. Morphological studies by electron microscopy showed that cells of Bacteroides succinogenes adhere firmly and intimately to cellulose and form layers over the cellulose fibre surface, and that these cells produce eroded grooves or pits on the surface. Attached cells could be detached by exposure to methylcellulose and this exposure halted digestion of the fibres completely. Methylcellulose does not inhibit growth of B. succinogenes upon substances to which the cells do not attach, e.g., soluble sugars, thus it is the detachment that is essentially responsible for the cessation of digestion of fibres. Additionally, methylcellulose only partially inhibits the action of the enzymes which are responsible for the digestion of fibres, and which are found on the bacterial cell surface. Thus, it appears that structures on the cell surface, other than the enzymes themselves, are responsible for the adhesion of the bacteria to the cellulose fibers. Cells of Ruminococcus flavefaciens showed a firm adhesion to cellulose fibres but did not show a specific orientation at the cellulose fibre surface, and detachment by methylcellulose was less effective. Cells of Ruminococcus albus exhibited a looser association with the cellulose fibre surface, and a less oriented distribution at this surface, but they were almost completely detached by methylcellulose.

Bacterial adhesion is of pivotal importance in the initiation and progression of digestion of the cellulose in straw, and the fact that each species has a specific and reversible mechanism of adhesion suggests that agents may be found that accelerate this process. Preliminary findings indicate that 3-phenylpropionic acid is such a promoter of bacterial adhesion and can cause an 8% increase in the rate and extent of straw digestion by mixed cultures of rumen bacteria. Promoting adhesion by chemical agents would shorten the "lag" phase which occurs during the process of adhesion and would accelerate the formation of a complete adherent cellulolytic bacterial population.

Even the most rapid in vitro cellulose digestion experiments with single species of bacteria do not yield rates of digestion as high as those observed with mixed natural populations in the functioning rumen. Many important processes in microbial ecology are accomplished by highly organized multi-species associations of bacteria. For this reason, we examined partially digested straw by electron microscopy

*Partially funded by a Farming for the Future grant.

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and observed layered populations in which the primary cellulolytic organisms (B. succinogenes, R. flavefaciens, and R. albus) were closely associated with spiral cells resembling Treponema and with curved cells resembling Butyrivibrio. Culturing the primary cellulolytic microorganisms with Treponema bryantii or with Butyrivibrio fibrisolvens in the presence of cellulose fibres increased cellulose digestion by up to 9%. Similar acceleration of cellulose digestion by fungi or protozoa by culturing these organisms with methanogenic or cellulolytic bacteria has been reported by others.

Thus, we have shown that primary cellulolytic bacteria and fungi adhere to cellulose fibres by specific mechanisms, which can be reversed and enhanced. As we achieve a more complete understanding of the nature of cellulolytic microbial associations, we will explore ways to promote the formation of adherent multispecies populations in order to accelerate further the digestion of cellulose in straw. In conjunction with chemical treatments and nutrient supplementation which have rendered straw marginally useful as feed, these new techniques will enable us to convert this under-utilized byproduct into an effective feed for ruminants.

EFFECT OF MEASUREMENT METHOD, TECHNICIAN, AND DISTANCE TRUCKED ON SCROTAL CIRCUMFERENCE OF BEEF BULLS

G. H. Coulter, R. J. Mapletoft[1] and G. C. Kozub

Variance of an individual scrotal circumference (SC) measurement was affected most by bull, while technician and measurement error components were much smaller. The Society for Theriogenology method of obtaining SC measurements was recommended for use in Canada. Trucking beef bulls either medium (138 km) or long (565 km) distances did not influence SC measurements when the Society for Theriogenology method was used.

Scrotal circumference (SC) has been used to accurately estimate paired testes weight, a reflection of the amount of sperm-producing tissue in bulls. Because of its relationship with sperm-producing potential, SC is a substantive component (40 out of 100 points) of the breeding soundness evaluation procedure established by the Society for Theriogenology. Many beef bull shows and sales in western Canada now establish minimum standards that bulls must meet or exceed before they are eligible for show or sale.

Three different methods of taking SC measurements, along with their respective standards, have been used in Canada. This has led to some confusion and misunderstanding when cattlemen familiar with one method encounter measurements taken with an alternative. Furthermore, cattlemen have often complained that bulls not attaining the required minimum standard when measured by the culling committee at a show or sale had a larger SC when measured before being trucked, or upon previous evaluation.

The purpose of this study was to examine the effects of method on SC measurements taken by different technicians with the objective of recommending the most suitable method for all breeds and applications within the beef industry, and to establish if trucking bulls over medium or long distances resulted in changes in SC.

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Two experiments were conducted. Experiment 1 was conducted at the Saskatchewan Central Beef Cattle Test Station, Saskatoon. Simmental (n = 21), Hereford (n = 18) and Charolais (n = 30) yearling bulls were used. Three technicians having limited or no experience taking SC measurements were instructed on the measurement method and then measured all bulls in a breed group. Bulls within the same breed group were measured by the same technicians a second and third time using the alternative measurement methods. This was repeated for the two remaining breed groups.

For each of the three methods used there was a significant effect of breed and technician on SC. The variance of an individual measurement was most greatly affected by bull with components due to technician and measurement error having a much smaller effect.

The resulting measurement method recommended for use throughout Canada was that of the Society for Theriogenology. That method involved the gentle but firm palpation of the testes down into the bottom of the scrotum so the scrotum was free of wrinkles and the testes were side by side. The thumb and fingers of one hand were placed on the anterior aspect of the testes-scrotum to cradle the scrotum and its contents. Care was taken not to grasp one testes with the thumb and fingers, which tends to separate the testes, or to tightly grasp the neck of the scrotum. Both of the latter techniques of stabilizing the testes introduce error. The looped scrotal tape was slipped up over the testes-scrotum and contracted around the largest circumference. Tension was then increased on the slider of the tape with the thumb until moderate resistance was provided by the testes-scrotum. Normally, the testes is a relatively firm, resilient organ that does not compress readily. The measurement was read in place following the application of moderate tension. Measurements obtained were taken to the nearest 0.5 cm. The technician component of variation was only 5.7% of the error component, indicating that the differences among technicians were small and relatively unimportant. The true measurement for a given bull would be expected to be within 1.1 cm of the measurement obtained with 90% predictability.

Experiment 2 was conducted in collaboration with the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture Canada. Two groups of bulls were used. Group 1, the medium distance group, was composed of 10 Charolais and two Hereford 2-year-old bulls. Group 2, the long distance group, was composed of two 3-year-old Charolais and 12 Charolais and two 2-year-old Hereford bulls. All bulls were maintained over winter at the PFRA Bull Station, Maple Creek, Saskatchewan. On the morning of the experiment the SC of all bulls was measured using the Theriogenology method before the bulls were loaded in flatbed, semi-trailer trucks. Group 1 bulls were trucked to the Swift Current-Webb, Saskatchewan PFRA Community Pasture, a distance of 138 km. Bulls were on the truck about 3.5 h before post-trucking measurement began. Group 2 bulls were trucked to the Ituna-Bon Accord, Saskatchewan PFRA Community Pasture, a distance of 565 km. These bulls were on the truck for about 10.75 h before post-trucking SC measurement began.

No differences ($P>0.05$) were observed in the SC trait when bulls were measured by the method recommended by the Society for Theriogenology after being trucked over medium or long distances. There was no indication that bulls having an SC below or at the recommended minimum standard reacted any differently to trucking stress than did bulls having a SC well above the recommended minimum standard.

The cause of the apparent reduction in SC reported by some cattlemen between measurements taken at home and those taken by culling committees following the trucking of bulls remains unknown. Possible explanations for the reduction in SC include: errors in SC measurement technique when measurements were taken at home, and effects of more severe weather conditions during trucking than those tested in the current experiment. Also, if SC measurements are taken several weeks before bulls are trucked to a show or sale, degeneration of the testes may occur in the interim. Beef bulls in the early stages of testicular degeneration could meet or exceed the minimum SC standard on initial measurement, yet be well under the minimum SC standard upon being presented to the culling committee owing to

continued testicular degeneration. Rapid degeneration of the testes over a short time interval is not uncommon, particularly in fat bulls.

These data support the use of the SC measurement technique recommended by the Society for Theriogenology, as this technique was consistent and was not influenced by trucking bulls over either medium or long distances.

SCROTAL CIRCUMFERENCE AND ITS HERITABILITY IN 2-YEAR-OLD BEEF BULLS OF SEVERAL BREEDS

G. H. Coulter, R. J. Mapletoft[1], G. C. Kozub, D. R. C. Bailey and W. F. Cates[1]

Based on this study, the recommended minimum acceptable scrotal circumference for 2-year-old bulls is Simmental, 36.0 cm; Angus and Charolais, 35.0 cm; Hereford, 34.0 cm; Shorthorn, 34.0 cm; and Limousin, 33.0 cm.

Breeding soundness evaluations are used to estimate reproductive potential of beef bulls for natural service. A major component of this evaluation is the scrotal circumference (SC) measurement (40 out of 100 points). Scrotal circumference is a good indicator of paired testes weight (r = 0.95) and of the amount of tissue with sperm-producing potential in young beef bulls.

To provide cattlemen with an accurate interpretation of a SC measurement, it is essential for the veterinary practitioner to understand the factors that can influence testicular development. Factors include bull age, body weight, season, and breed. Most reports of breed effects on SC pertain to yearling bulls and some breeds of older bulls. Little information is available for these effects on 2-year-old beef bulls or on the heritability (h^2) of the SC trait in 2-year-old bulls. Such data would provide an indication of how quickly the SC trait might respond to selection when measured at 2 years of age. Recommendations for minimum acceptable SC for beef bulls of different breeds apparently do not exist in the scientific literature.

This report presents the results of a field study to examine the effect of breed on SC of 2-year-old beef bulls and to estimate the h^2 of the SC trait in 2-year-old beef bulls of some breeds. In order to establish some consistency within the beef industry and to exert some degree of selection pressure for SC, we have also presented recommended minimum acceptable SC measurements for 2-year-old bulls.

Scrotal circumference was measured on 7918 2-year-old beef bulls of the Aberdeen Angus (n = 629), Charolais (n = 499), horned Hereford (n = 3769), polled Hereford (n = 2170), Limousin (n = 80), Shorthorn (n = 231), and Simmental (n = 540) breeds. Measurements of SC were taken as part of a pre-show/sale evaluation by a culling committee.

[1]Western College of Veterinary Medicine, Saskatoon, Saskatchewan

Scrotal circumference measurements taken at a particular bull sale in one year represented one location-year. Twenty-one location-years were represented in total. Scrotal measurements were taken using the measurement technique recommended by the Society for Theriogenology or other measurement techniques converted to that of the Society. The Society for Theriogenology SC measurement technique is described in the preceding article.

Only SC data from bulls within the age range from 608 to 852 d (24%4 mo) were used. The SC measurements were analyzed statistically for each breed using an analysis of covariance with random effects of location-year and sires: the covariate age was also included in the statistical model. The SC measurements were adjusted to a common age of 730 d and an estimate of SC was obtained for each breed. An analysis across breeds was carried out by adding the effect of breed in the model.

The h^2 estimates of the SC trait in 2-year-old beef bulls were estimated from measurements on 7835 2-year-old bulls from 2570 sires within the field study described above. Heritability was estimated from the paternal half-sib correlation.

The mean age of the 7918 bulls used in the study was 724 d (range 608 to 846 d). Statistical analyses of SC measurements within each breed showed that effects due to sires and location-year generally accounted for most of the variation in SC ($P < 0.01$). Differences due to technician used to take the SC measurements were included as part of the location-year effect. Age had a minor although significant ($P < 0.05$) effect for polled Hereford, Limousin, and Simmental breeds. Bulls that were older tended to have larger SC. The SC was adjusted within breed to a common bull age of 730 d. Adjusted mean SC for the seven breeds of 2-year-old bulls are presented (Table 1).

Breed must be considered when interpreting a SC measurement. A SC measurement of 36.0 cm for a 2-year-old Limousin bull is well above the average for this breed, but it is below average and is not recommended for both the Angus and Simmental breeds.

Heritability estimates for the SC of six breeds are also presented in Table 1. For some of the breeds in this study, there were not large numbers of sires or sons within sires. For such groups, the corresponding estimates for h^2 of the SC trait will not be precise and should be viewed with caution. However, they can be used to indicate approximate levels of h^2 for a particular breed. The h^2 of SC for Angus and Simmental 2-year-old bulls are not significant. By 2 years of age, SC for Angus and Simmental appears not to

Table 1. Mean scrotal circumference (SC), minimum recommended SC, and heritability estimates for SC in several breeds of 2-year-old beef bulls.

Breed	No. of bulls	Mean[1] SC%SE(cm)	Range SC(cm)	Minimum recommended SC(cm)	Heritability of SC	
					df for sires	h^2(%SE)
Simmental	540	38.8%0.10	29.0-47.0	36.0	244	0.20%0.24
Aberdeen Angus	629	37.2%0.09	28.3-47.0	35.0	270	0.00%0.21
Charolais	499	36.3%0.09	28.5-44.0	35.0	232	0.60%0.25
Hereford (horned)	3769	36.1%0.03	26.0-47.0	34.0	1037	0.57%0.07
Hereford (polled)	2170	35.6%0.04	25.0-45.5	34.0	692	0.65%0.10
Shorthorn	231	34.9%0.11	28.0-41.0	34.0	89	0.69%0.34
Limousin	80	32.2%0.18	25.0-37.0	33.0		

[1]Estimates of SC adjusted to 730 days of age and corrected for location-year and sire effects.

be heritable. By that age testicular development in these breeds may be closely approaching mature size, which may be generally uniform across bulls within the breed whether they had the genetic potential to grow at either a slow or fast rate at a younger age. The h^2 estimates for SC for horned and polled Hereford 2-year-old bulls are most precise due to the large number of sires representing these two breeds.

Our recommended minimum SC measurements by breed are presented in Table 1. Recommended measurements are generally one standard deviation below the mean for each breed group rounded up to the nearest 1.0 cm to exert some selection pressure on the trait. If these recommended minimum standards are followed, 16 to 20% of bulls with the smallest SC will be culled. An exception to this is the Limousin breed where the recommended minimum SC (33.0 cm for 2-year-old bulls) is greater than the mean (32.2 ± 0.18 cm). We believe that added selection pressure on testicular size in Limousin bulls would benefit the breed. Initially, it may be desirable to establish a minimum standard below that recommended here for the Limousin breed and to increase the minimum over a period of time until the 33.0 cm minimum is attained. The probability of beef bulls having satisfactory seminal quality has been demonstrated to increase linearly as SC increases from less than 30.0 cm to the minimum standards recommended here. Cattlemen selecting herd sires should seriously consider selecting bulls having SC substantially greater than the minimums listed, perhaps closer to the mean SC for the breed.

Although a great deal of attention has been paid to the potential fertility of bulls, an even greater benefit of using bulls with above-average testicular size is the positive carryover to reproductive traits in female progeny. Heifers sired by bulls with above-average testicular size for their age and breed attained puberty at a younger age, were more fertile, and were expected to have higher lifetime productivity. These benefits may not be realized by using sires that have slow but prolonged testicular growth. We recommend that bulls meet, and preferably exceed, the minimum SC measurements listed. However, the effects of selecting bulls with extremely large testicles, greater than three standard deviations above the mean, on bull reproductive capacity and on the fertility of female progeny are unknown. Caution should be exercised when selecting bulls with extremely large testicles. As with other traits in our domestic species, selection carried to the extreme may be detrimental.

CATTLE WEIGHT GAINS ON FESCUE GRASSLAND

W. D. Willms and S. Smoliak

Individual animal gains over a 6-month grazing period on fescue grassland were maximum at a stocking rate of 1.6 animal unit months (AUM)/ha or less. Although cattle gains, on a unit area basis, increased with an increase in stocking rate to 4.8 AUM/ha, this rate could not be maintained since forage production was reduced below that required for animal maintenance. Rough Fescue Grasslands should not be stocked at rates heavier than 2.4 AUM/ha for optimum cattle production.

The Rough Fescue Grasslands are highly productive and represent essential rangeland for cattle production in the foothills. However, the important native grasses of this area are very sensitive to grazing and are readily replaced with less productive species. Since revegetation is expensive and often not possible owing to the rugged terrain of the foothills, future production is dependent on native species. Consequently, a study was made to determine the stocking rate that would result in optimum sustained cattle production.

The study was made at the Stavely Range Research Substation from 1949 to 1983. Four fields were fenced and stocked with 13 cows, with calves, for a 6-month period at rates (AUM/ha) that were very heavy (VH, 4.8), heavy (H, 2.4), moderate (M, 1.6), or light (L, 1.2). Cows and calves were weighed at monthly intervals during the grazing season from May 15 to November 15. The calves were weaned after the grazing season in mid-November. Forage production and utilization were estimated from 1972 to 1981 by harvesting paired caged/uncaged plots, after the grazing season.

The stocking rate in field VH was 4.8 AUM/ha from 1949 to 1959 but was adjusted yearly after that to avoid animal losses. Cattle were removed from the field when they first lost weight. This resulted in stocking rates that varied from 2.5 to 4.8 AUM/ha and averaged 3.2 AUM/ha for the period from 1960 to 1983.

Cattle gains per hectare were 17, 23, 27, and 49 kg for cows, and 28, 39, 55 and 83 kg for calves in fields L, M, H, and VH, respectively. Average production (and percent utilization) was 2200 (26%), 2170 (36%), 1865 (47%), and 1170 (81%) kg/ha for the above fields, respectively. Cows lost weight when residual forage on this range was less than 280 kg/ha. Average daily gains for cows were maximum in spring and declined to a negative gain by fall (Fig. 1). Weight gains of calves were maximum in August and minimum, but not negative, in fall. Weaning the calves in early September would take advantage of the period of rapid gain for calves while reducing the energy requirement of the cows.

Individual cattle weight gains over the grazing season were defined by the unit available forage (UAF), which is the total available forage in a field allocated to each animal unit for the grazing season (Fig. 2). The UAF varied from 700 to 16,000 kg; however, animal weight gains showed little noticeable response after 5000 kg. Maximum gains achieved were 152 kg by calves and 112 kg by cows.

Long-term stocking at a fixed rate affected the carrying capacity of the range (Table 1). Fields that had been stocked at 2.4 AUM/ha or less could support a higher stocking rate for a short-term if necessary. However, stocking in field VH was restricted to a rate less than 4.8 AUM/ha and was determined by the annual precipitation for the year. Consequently, although beef production per unit area was greatest from field VH, management flexibility was lost since forage production was unpredictable and the cattle were able to graze the field only for about 3 months.

Rough Fescue Grassland will support between 1.6 and 2.4 AUM/ha on a sustained basis. However, the heavier

stocking rate will result in a loss of forage production that may not be acceptable on public lands. Range in good condition can support a stocking rate of 4.8 AUM/ha only for a period of about 10 years before the stocking rate must be reduced. The condition of the cows would likely be enhanced if the calves were weaned in early September.

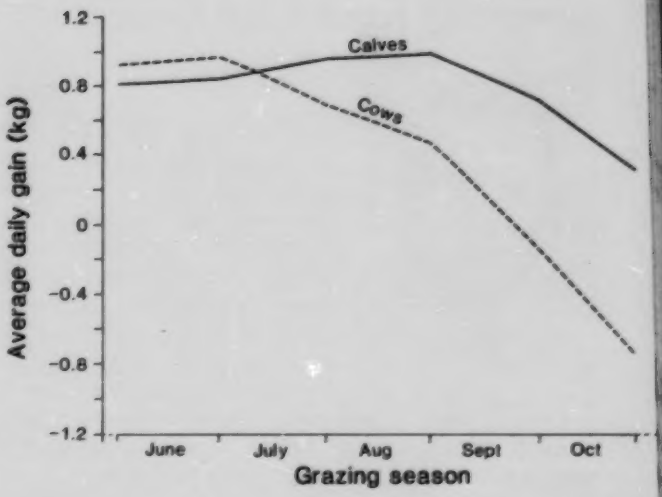

Fig. 1. Average daily gain of cows and calves over the grazing season on Rough Fescue Grasslands.

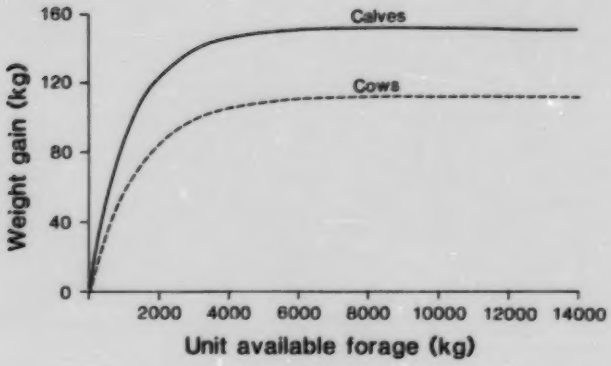

Fig. 2. Weight gains of cows and calves in relation to available forage on Rough Fescue Grasslands.

Table 1. Calf gains in relation to set stocking rates over the long term and short term, calculated for one hectare.

Long-term effects			Short-term effects			
					Calf gain (kg)	
AUM[1]	AU	Available forage (kg)	AUM[1]	Forage require-ments[2]	/indiv.	/ha
1.2	0.20	1920	1.2	396	152	30
			2.4	792	149	60
			4.8	1584	134	107
1.6	0.27	1890	1.2	396	152	30
			2.4	792	150	60
			4.8	1584	133	106
2.4	0.40	1585	1.2	396	152	30
			2.4	792	147	59
			4.8	1584	125	100
4.8	0.80	890	1.2	396	149	30
			2.4	792	131	52
			4.8	1584	95	76

[1]Stocking rate, in animal unit months.
[2]Based on 11 kg per day per AUM for 6 months.

PRODUCTIVITY OF EXOTIC-CROSS BEEF COWS IN TWO ENVIRONMENTS

J. E. Lawson

European x British breed (exotic) crosses of the 10 combinations studied performed differently in range and parkland environments. Body condition was very important, along with body weight, in determining winter feed requirements if backfat was less than 5 mm. Simmental- and Charolais-sired crosses were the most productive, and Simmental crosses the most efficient, whereas Limousin-sired crosses were relatively unproductive and inefficient in both environments.

Crossbreeding of beef cattle can improve reproductive and growth traits, promote adaptability to new environments, and provide the basis for new breeds. Traditionally, crossbreds derived from British breeds have had higher conception rates and have produced heavier weaning weights than straightbred cattle.

Direct importations of breeding stock to Canada from the cattle herds of Continental Europe followed the opening of the first quarantine stations in Canada in 1965. Importers were looking for increased size, lean meat, and milk production. Charolais were imported first, followed by Simmental in 1967, and Limousin in 1968.

In 1969, the Research Branch of Agriculture Canada through its Research Stations at Lethbridge, Lacombe, and Brandon began to evaluate the breeds in a crossing program. Cooperating ranchers produced 10 specific types of first-cross heifers: the Hereford-Angus (HA), and the nine crosses sired by Charolais (C), Limousin (L), and Simmental (S) out of Angus (A), Hereford (H), and Shorthorn (N) dams. The Brandon and Lacombe Stations developed the 1150 heifers to breeding age. Heifers of each cross were then divided equally between the extensive range environment at the Onefour Research Substation near Manyberries in southeastern Alberta and the semi-intensive parkland environment at Brandon, Manitoba. Cows were evaluated for reproductive capabilities and for growth and carcass characteristics of their >4000 calves produced from 1972 through 1978. Several aspects of productivity were evaluated.

Findings indicated a relatively high level of performance at both Onefour and Brandon for crossbred cows sired by Charolais. The relatively poor performance of the Limousin-sired cows was a function of heavier culling of cows, higher postnatal calf mortality, and a slower growth rate of calves to weaning. Simmental-sired cows produced the greatest weight of calf weaned per mating opportunity at Brandon. Simmental-sired cows produced the heaviest calves at weaning at both locations but at Onefour their average weight of calf weaned per mating opportunity was less than that for Charolais-sired cows. Charolais crosses weaned nearly 6% more calves. This is one example of how crossbreeding with high-producing exotic-crosses can reduce rather than enhance reproductive capabilities.

The production potential of these exotic-crosses has been well established. However, the energy requirement for both maintenance and the relatively high production achieved by some of these exotic-crosses was not well known.

In a 4-year study, energy inputs were measured for each of the 10 breed-crosses for maintenance during the period from weaning to the following calving (about 147 days) at Brandon and Onefour. National Research Council (NRC) recommendations were used as a base to estimate the energy requirements for cows of a given weight. Feed allotments were increased during occasional periods of severely cold weather, when it was necessary to upgrade the condition of cows that were initially thin or had lost condition during the previous 28-day period, and to accommodate fetal growth in the last 2 months of pregnancy. Brandon fed primarily barley or corn silage while Onefour fed a hay cube comprised of 70% alfalfa and 30% straw. The hay cube was a particularly useful feed source because it was of consistently high quality and little was wasted by the cattle.

In the first winter, the average backfat, as measured by an ultrasonic instrument, was 4.3 mm at Onefour and 10.8 mm at Brandon. Although energy inputs were increased to 20% above NRC recommendations at Onefour, cows continued to lose condition. Ultimately, it was observed that cows needed at least 5 mm of backfat during the winter if they were to successfully compete for feed, survive, calve without difficulty, and then conceive readily the following summer. The second winter, feed inputs at Onefour were increased to 40% above NRC recommendations. This was followed by a decrease in cow and calf losses and an increase in conception rate from 67 to 91%. These problems did not occur at Brandon, where the condition of the cows was relatively better.

Body weight differences for mature cows varied among years because of differences in grazing conditions. At Onefour, the percentage by which each of the exotic crosses exceeded the HA (average about 508 kg) following a summer on pasture is indicated in Table 1. At Brandon, the HA (average about 544 kg) was exceeded by the three Charolais-sired crosses by 13 to 17%, the three Simmental-sired crosses by 7 to 8%, and the three Limousin-sired crosses by 6 to 8%.

Weight advantages existed for the exotic-crosses even though the HA crosses were carrying the most backfat at weaning. At Onefour the HA ranged from 5.0 to 8.5 mm of backfat over the 4 years, while ranges (in mm) for the other breed-cross groups averaged less (Table 1). Backfat at Brandon averaged 9.8-13.2 mm. Individual crosses never averaged less than 6.1 nor more than 11.3 mm. Simmental-crosses carried the least backfat. Brandon cows carried sufficient backfat to counteract severe winter weather and to assure strong cows at calving and good conception rates the following summer.

The cost of feed for cows in western Canada is accounted for chiefly during the winter maintenance period. For this reason, cow efficiency (weight of calf weaned per mating opportunity divided into the megacalories (Mcal) of digestible energy (DE) consumed) was calculated for each breed-cross. For weight of calf weaned per mating opportunity, the Brandon herd averaged 170 kg compared with 142 kg at Onefour. Winter feed inputs averaged 3643 Mcal DE per cow at Onefour and 3197 at Brandon. These combinations resulted in an average "efficiency" estimate of 18.79 Mcal DE/kg of calf at Brandon compared with 25.58 at Onefour. This reflected the poorer

Table 1. Percent advantage over Hereford-Angus for body weight at weaning of exotic crosses and range of yearly backfat averages at weaning[1].

	Body weight[2] (% advantage)	Backfat (mm)
Charolais x Hereford	19	3.9-6.2
Charolais x Angus	11	2.9-4.3
Charolais x Shorthorn	16	3.2-5.1
Simmental x Hereford	13	3.8-5.0
Simmental x Angus	11	3.0-5.1
Simmental x Shorthorn	9	2.5-4.5
Limousin x Hereford	9	4.5-6.1
Limousin x Angus	1	3.6-5.9
Limousin x Shorthorn	6	3.8-4.8

[1]Cattle maintained on range at Onefour Substation.

[2]Percentage greater than Hereford x Angus (avg. 508 kg).

condition of cows at Onefour and the need to increase feed inputs. The HA crosses were lighter than other crosses and required correspondingly less feed inputs for winter maintenance. At Onefour, however, the LH (8%) and the LA (3%) were less efficient than the HA. The CA and SA (8-9%) and the CH, CN, SH, and SN (3-4%) were more efficient. At Brandon, the CH and LA were 8% less efficient than the HA, while the three Simmental crosses were 4-8% more efficient. The other four crosses were essentially the same as the HA.

Some observations are:

1. When the feed supply on summer pasture was less than optimal some exotic crosses were in poor condition. Unless they received relatively high levels of winter feed, they were reluctant to compete for feed, too weak to calve, and had a lower reproductive rate. When this situation occurs early weaning should be considered as a measure to help cows to regain condition before winter.
2. Limousin-sired crosses had relatively low productivity in both environments.
3. Body weight was an acceptable indicator of feed requirements if condition was adequate, but if condition was relatively poor (less than 5 mm of backfat), an increase in feeding levels was of paramount importance.
4. Even though the condition of the HA at weaning was adequate at both locations, and therefore major increases in feed inputs were not required for that group relative to the exotic-crosses, the exotic-crosses were relatively more efficient than the HA at Onefour than at Brandon.
5. Only the three Simmental groups were relatively more efficient than the HA at both locations.
6. Although Onefour is located in the short-grass prairie, these performance results are basically an indication of the limitations in feed supply. Results can probably be transferred to other environments where similar feed limitations exist.

REPRODUCTIVE PERFORMANCE OF CROSSBRED AND PUREBRED DAIRY COWS

J. A. Vesely

The number of dead calves delivered by purebred cows did not depend on whether or not the calf was purebred or crossbred or if it was born following the first, second, third, or fourth gestation. However, Holstein cows had higher mortalities of calves than Ayrshire or crossbred cows, and more abnormal births than cows in other genetic groups. Placental condition did not vary among the genetic groups of cows. Means for days to first service, number of services per conception, calving interval, and gestation period were almost identical for all genetic groups.

Management for high milk production places dairy cattle under stress. Concern about the reproductive problems and the economic losses incurred has grown with increased milk production by cows. Reproduction failure now accounts for an estimated 16 to 32% of all disposals and ranks second only to low production as the major reason for cows leaving the herd. As inbreeding reduces the mean phenotypic values of characters connected with reproductive capacity, animal breeders expect improvement in reproductive traits by crossbreeding. However, results of crossbreeding experiments with dairy cattle have been variable and inconclusive. Any apparent improvements have been of minor practical importance.

The Research Branch of Agriculture Canada has been conducting a selection and crossbreeding experiment with dairy cattle since 1972. The purpose of the current study was to estimate the effect of crossbreeding on reproduction based on traits of cows through their fourth gestation.

Data were collected from an ongoing Research Branch dairy cattle breeding project involving five stations (Animal Research Centre at Ottawa, Ontario; Research Stations at Charlottetown, P.E.I., Lennoxville, Quebec, and Lethbridge, Alberta; and Experimental Farm at Normandin, Quebec). The Research Branch Holstein cows were initially inseminated with semen from Research Branch, Canadian, and U.S. Holstein bulls to create H-line foundation animals. The Research Branch Ayrshire cows were inseminated with semen from Research Branch, Canadian, U.S., and Finnish Ayrshire as well as U.S. Brown Swiss and Norwegian Red bulls to create A-line foundation animals. The two closed lines are referred to as H and A lines. Concurrent with the within-line breeding, about one-third of each of the H- and A-line females were mated to bulls of the other line to produce crossbred animals. This study involved cows of H- and A-lines delivering straightbred or crossbred calves, and subsequently, F_1 cows from the crossbred calves, delivering crossbred calves. The traits analyzed were number of calves born dead, kind of birth, placental condition, calving interval, gestation length, number of days to first service, and number of services for conception.

The number of dead calves did not depend on whether the calf was purebred or crossbred or born at the first, second, third, or fourth parturition. The effect of genotype of calf had little effect on the kind of birth or placental condition. There were fewer normal births ($P < 0.01$) at the first than at subsequent parturitions. The fewer normal births at first parturition were due to higher calving problems of Holstein cows having Holstein calves. The genotype of calf had no significant effect on placental condition at any parturition. The effect of genetic group of cow on mortality of calves was more pronounced than the effect of genetic group of calf. Holstein cows had significantly higher mortalities of calves than Ayrshire or crossbred cows (Table 1). Holstein cows also had a lower percentage of normal births at first parturition than did cows of the other genetic groups. Placental condition did not vary among the genetic groups of cows except those at first parturition (Table 2). Reproductive

Table 1. Percentage incidence of dead calves at birth from purebred and crossbred cows from first to fourth parturitions.

Genotype of cows[1]	Male calves born dead					Female calves born dead				
	1	2	3	4	Overall	1	2	3	4	Overall
H x H	16.0	9.4	13.0	3.8	12.0	13.0	5.8	5.9	8.4	9.0
H x A; A x H	7.9	2.5	4.0	1.8	4.7	4.9	4.8	3.2	1.9	4.2
A x A	8.2	7.1	1.6	9.7	7.0	7.1	1.8	10.0	4.0	5.7
	**	*	**	NS	**	*	NS	NS	NS	**

[1]H = H line, A = A line.
* = $P < 0.05$; ** = $P < 0.01$; NS = not significant.

Table 2. Percentage incidence of kinds of birth and placental conditions in purebred and crossbred cows from first to fourth parturitions.

Genotype of cow[1]	Kind of birth			Placental condition		
	Normal	Abnormal	Other	Normal	Retained	Abortion
			First parturition (%)			
H x H	69.0	29.9	1.1	90.3	8.6	1.1
H x A; A x H	79.3	19.3	1.4	89.5	9.1	1.4
A x A	76.0	23.1	.8	84.0	15.2	.8
	**	**	NS	*	*	NS
			Second parturition (%)			
H x H	89.9	9.2	.9	87.4	11.7	.9
H x A; A x H	92.4	6.5	1.1	88.1	10.8	1.1
A x A	94.0	3.7	2.3	81.7	16.0	2.3
	NS	NS	NS	NS	NS	NS
			Third parturition (%)			
H x H	86.4	10.6	2.9	78.0	19.0	3.0
H x A; A x H	89.5	9.5	1.0	82.6	16.3	1.1
A x A	92.7	6.4	.9	75.5	23.6	.9
	NS	NS	NS	NS	NS	NS
			Fourth parturition (%)			
H x H	82.8	15.2	2.0	74.5	23.4	2.1
H x A; A x H	95.2	4.8	0	75.2	24.8	0
A x A	83.6	14.5	1.9	70.9	27.3	1.8
	NS	NS	NS	NS	NS	NS

[1]H = H line, A = A line.
* = $P < 0.05$; ** = $P < 0.01$; NS = not significant.

traits, such as days to first service, number of services per conception, calving interval, and gestation length, did not demonstrate heterosis. Means for these traits for each genetic group of cows were almost identical, although the means for crossbred cows for days to first service, number of services per conception, and calving interval were the lowest.

In summary, it is concluded that crossbreeding with dairy cattle does not improve the cow's ability to conceive or the efficiency of achieving conception. However, the results presented here on higher rate of survival of calves from crossbred cows, particularly in comparison with Holstein cows, give evidence of an apparent economically important difference in net reproductive rate in favor of crossbred over Holstein cows.

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PERFORMANCE OF CROSSBRED LAMBS

J. A. Vesely

Romanov crossbred females can be very useful in increasing the production of lambs in commercial breeding flocks. That benefit could be eroded if the Romanov crossbred males that are fed out for slaughter have inferior growth or carcass quality. However, carcass quality is similar for lambs sired by Finnish Landrace, Romanov, and Dorset Horn, and in overall productivity the Romanov crosses best with the Western Range ewes.

The Romanov breed of sheep is well known for its high prolificacy of 2.5 or more lambs per ewe. The immediate value of this breed in Canada would be in the use of rams to produce crossbred females from ewes of native breeds. The crossbred females would, in turn, be bred to terminal sires of the mutton breeds. Romanov crossbred lambs from Canadian native breeds of ewes, however, are not known for their growth and carcass quality. This article presents results on growth performance, survival rate and carcass quality of crossbred Romanov lambs in comparison with other crossbreds.

Three-quarter Dorset, 3/4 Finn, and Western Range ewes were sired by Dorset, Finn, Romanov, and Western Range rams. These matings produced the following offspring: Dorset x 3/4 Dorset (DD), Dorset x 3/4 Finn (DF), Finn x 3/4 Dorset (FD), Finn x 3/4 Finn (FF), Romanov x 3/4 Dorset (RD), Romanov x 3/4 Finn (RF), Romanov x Western (RW), and Western x Western (WW).

The heaviest lambs at birth were the Western (WW) lambs. The lightest lambs were out of the crosses with Finn dams (DF and RF) (Table 1). Survival rate of lambs from birth to weaning varied little among the eight genetic types. The only significant difference existed between the cross with the highest survival rate (RW) and the cross with the lowest survival rate (FD). The heaviest weaning weights were those of DD lambs. The lightest were of DF, FD, and RF lambs, while the intermediate weights were of FF, RD, RW, and WW lambs (Table 1). Body gain in feedlot from weaning to slaughter did not show the expected compensatory response. The heaviest lambs at weaning (DD, FF, RD,

RW, WW) were also the fastest gaining in the feedlot. The longest period of time spent in the feedlot was about 120 d for Finn crosses (DF, FD, RF). Lambs of DD, RD, RW and FF breeding spent the least number of days in the feedlot (about 110 d). Results of the carcass study (by carcass grades, not shown in table) indicated that crossbred lambs sired by Finn or Romanov rams have carcass quality similar to that of lambs sired by Dorset Horn.

Results of this study give a strong indication that the Romanov breed may cross best with Western range ewes because, unlike the other genetic types, they performed well for almost all traits studied.

Table 1. Least-squares means of birth weight, survival rate, weaning weight, average daily gain (ADG), final feedlot weight and number of days in feedlot of eight genetic types of crossbred lambs adjusted for age of dam, sex, weaning type, crop[1] and management[1].

	Trait					
Cross	Birth wt, kg	Survival rate, %	Weaning wt, kg	ADG, g	Final wt, kg	Days in feedlot
DD	3.7b[2]	84	16.7a	252bcd	44.6abc	111.2cd
DF	2.8e	81	13.6c	248bc	43.9d	125.3a
FD	3.0d	78b	14.4b	250bc	44.1cd	121.1ab
FF	3.4c	85	15.8a	258ad	44.8abc	108.7d
RD	3.4c	82	16.0a	243c	44.3bcd	112.1cd
RF	2.9e	83	14.1cb	245c	43.8d	122.5a
RW	3.8b	86a	16.0a	263a	44.8ab	112.5d
WW	4.1a	82	15.7a	262a	45.2a	121.9ab

[1] Lambs were born during a 2-year experiment in seven different crops with two managements within each crop.

[2] Means with the same superscripts within column do not differ.

FUTURE DEVELOPMENTS IN RUMINANT PRODUCTION

L. M. Rode, G. H. Coulter, G. J. Mears and J. E. Lawson

Several areas of animal nutrition, physiology, and genetics are currently limiting ruminant production. Research in certain areas promises tremendous advances in productivity. However, advances in one area will be associated with negative effects in other areas. Thus, progress in long-term production will continue to be made in small increments rather than in quantum leaps.

Many of the ruminant production levels acceptable by today's standards would have been considered beyond the biological limit for ruminants 25 years ago, yet the basic genetic and biochemical processes within the ruminant are unchanged. Advances in production have been achieved by overcoming certain biological and environmental constraints, but maximum production is still limited by further biological constraints.

It may not be practical to reduce or eliminate a constraint to the theoretical production limit because an increase in productivity in one area may result in a decrease in productivity in another, or the unit cost of the increased productivity may be prohibitive. Markets for commodities of ruminant production are stable or are declining. For this reason, the goals of future research must be oriented toward generating saleable products more efficiently or in a more cost-effective manner. Researchers at the Lethbridge Research Station are conducting experiments in the following areas to help producers eliminate factors limiting ruminant production.

A major determinant of animal production is voluntary feed consumption (VFC), as it establishes the level of nutrients that will be available for productive or maintenance functions. Voluntary feed consumption is regulated by rumen digesta fill, rate of passage, and rate of digestibility with forage-based diets.

Rumen fill is directly related to body weight. Relatively small animals cannot eat as much and will not be as productive on good nutritional regimes as larger animals, whereas larger animals are at a disadvantage when feed resources are limited in quality or quantity because of their greater energy requirements. In the Agriculture Canada Foreign Cattle Breed Evaluation project, the relative advantage in lifetime productivity of the larger, heavier milking continental crosses compared with the smaller British crosses was smaller in the rigorous rangeland conditions of southern Alberta than in the less demanding parkland environment in southern Manitoba.

Increasing rate of passage or rate of digestion will increase digestible dry matter intake of forages. Particle size reduction is the major limiting process controlling passage rate of particles from the rumen. Physical processing of fibrous feedstuffs is an effective means of aiding reduction of particles outside the rumen and increasing their rate of passage from the rumen, but it actually circumvents the biological constraint of feed particle size on VFC. Biologically, mastication during eating and rumination is the primary avenue of particle size reduction utilized by ruminants. Animals are unable to spend more than 10-12 h/day ruminating. Thus, efficiency of rumination is the controlling factor in particle size reduction and therefore VFC of high-forage diets. Cattle are more efficient in reducing the size of plant cell wall particles than sheep, and large cattle are more efficient than small cattle. Rate of feed digestion in the rumen is controlled by inherent characteristics of the feed. However, physical attachment of microbes to feed particles is necessary for most fiber digestion. Experiments at the Lethbridge Research Station have shown that it may be possible to "train" rumen bacteria to digest cellulosic feedstuffs more rapidly.

Recent developments in biotechnology have created interest in the genetic manipulation of rumen microorganisms to produce a wide variety of additional end products and enzymes that may be beneficial to ruminant production. For the most part, this will place additional demands on the altered microbes, which may make them unable to compete and proliferate in the rumen environment. A more beneficial and realistic approach may be to manipulate rumen microbes, genetically or otherwise, to increase the rate of microbial attachment and fiber digestion and thus decrease the time required for the initiation of digestion. Improved knowledge of rumen function is a key to improvement of ruminant productivity.

As much as 75% of the total annual energy requirements for beef cows are required for maintenance functions. Maintenance requirements have been positively associated with the genetic potential of an animal for growth rate or milk production. Cattle with a genetic potential for rapid growth or milk production have a greater proportion of body weight as liver and digestive tract, consume more feed and have a greater maintenance requirement per unit body weight. Apparent maintenance requirements could be reduced by 10-30% if animals could handle high levels of feed intake without increasing the relative weights of high energy-using organs such as the liver and digestive tract. Although conceptually possible, it is unlikely that this is an achievable selection goal. Therefore, the energy requirement for maintenance is a biological constraint that cannot be manipulated.

Animals differ in their ability to partition nutrients between milk and tissue synthesis and between adipose and muscle synthesis. Therefore, an excellent opportunity for improving productive efficiency lies in the manipulation of nutrient supply at the tissue level. Considerable excitement has been generated around the potential of exogenous growth hormone (GH) to increase milk production in cows and protein accretion in growing ruminants. Several studies have shown large responses in milk production of dairy cows injected with exogenous GH. This has led to claims of increased efficiency of production. In fact, apparent productive efficiency is improved because the energy cost of maintenance is spread over more milk production per cow when exogenous GH is administered but the true biological efficiency of the extra production is unchanged.

We know very little about how hormone systems affect the various physiological processes within the animal. We know that GH is necessary for an animal to achieve normal mature size, but we do not know if rapid growth is expressed through the secretion or through the turnover of this hormone. Recently, attempts have been made to modulate the secretion and turnover of growth hormone in the lamb by inducing the production of antibodies to somatostatin, a peptide that inhibits GH secretion. In some instances this has increased growth rates. Thus, it would appear that this mechanism can be manipulated to allow an animal to more closely reach maximum expression of its genetic potential for growth. Presumably, many of the physiological systems involved in ruminant production can be manipulated to maximize their genetic expression once we learn which ones are involved and more about the mechanisms themselves.

Caution must be exercised in the anticipation of dramatic production responses from GH or other hormonal manipulation. Growth hormone causes a low-producing cow to enter the same state of negative energy balance associated with high-producing cows at peak lactation. If these cows are not capable of replacing the tissue expended during the period of negative energy balance, consequences for subsequent conception and milk production may be disastrous.

The tendency is to view the physiological constraint of ruminant production as a postnatal problem. However, there is growing evidence that constraints can occur in utero as well. For example, mortality rates are higher in lambs with birth weights below the breed norm, and absolute growth rates are lower in surviving lambs that are lighter at birth than their breed counterparts. Also, calves that are heavier at birth have a higher lean to fat ratio at slaughter, and therefore

are more productive in terms of lean meat production than calves that are lighter at birth. Plane of maternal nutrition and placental size are recognized as the major determinants of fetal growth. In well fed ewes the rate of fetal growth is positively correlated with placental size after 120 days of gestation. Therefore, the placental supply of nutrients apparently limits fetal growth before the end of pregnancy.

Understanding the biological constraints in reproduction is a prerequisite to consideration of constraints associated with genetics, nutrition and physiology. It has been established that the economic value of reproductive merit, growth performance, and product quality are in the ratio of 10:2:1 in relative importance to the beef industry, while sterility is the second most frequent cause of culling in dairy herds.

Fertility is generally accepted to have a heritability approaching zero but this is a biological constraint that can be overcome. The genetic correlation between testicular size in the beef bull, as measured by scrotal circumference, and age at puberty in either female half sibs or progeny ranges from -0.71 to -1.07. This suggests that selection for increased testicular size in bulls will reduce age at puberty in female progeny. Consequently, there is an increase in the probability of conception in females bred for the first time as yearlings and an increase in potential lifetime productivity.

The ability of an animal to reproduce and be productive is significantly influenced by the environment in which the animal is expected to perform. For example, straightbred Brahman or Shorthorn are unable to perform well or even survive in a rigorous range environment in southern Alberta, whereas the intermating of the two resulted in a well adapted, high-performing cross.

One factor that must be considered when examining the biological constraints of ruminant production is the male to female ratio commonly used in breeding herds. Under current natural breeding conditions, the bovine female will produce one or possibly two progeny per year. Through superovulation, embryo manipulation, embryo sexing, and embryo transplantation the number of offspring per female can be increased moderately, but at a relatively high cost that is often not economically advantageous. By contrast, the bull or ram has the potential to sire tens of thousands of progeny per year through artificial insemination. Even when natural service is used, 30 to 100 females can be bred. As relatively few males are required to impregnate many females, the selection pressure on available males for reproductive and productive traits can be great and of significant benefit to the industry.

Superovulation, nonsurgical embryo collection and the development of embryo manipulation techniques have greatly reduced and will continue to reduce the biological constraints to expanding reproductive potential of the female. However, these technological advances may have limited impact because of the economics of ruminant production. Embryo manipulation techniques may accomplish developments such as incorporation of desirable nucleotide sequences, or the crossing of two different males by placing two sperm in the ovum and remodelling the female pronucleus. However, these techniques are likely to be applied to a very limited number of animals. This will still necessitate using primarily the male to disseminate the genotypic advantages obtained.

In general, the authors are apprehensive that many of the advances optimistically suggested by bioengineers are not going to be as beneficial to the ruminant as claimed. The ruminant is a complex interrelationship of many mechanisms. Vast changes in any one system are sure to be reflected in other areas and not necessarily to the net benefit of the animal and its productive capacity. These inter-relationships must be thoroughly studied before proceeding to change current breeding and management practices.

Increases in voluntary feed consumption will be of little benefit if maintenance requirements for energy are also increased. Likewise, hormonal

manipulation that results in improved milk production or growth rate will be meaningless in terms of lifetime productivity if the added stress hinders reproductive performance. For these reasons, new technologies and advancements that promise tremendous gains in productivity should be embraced cautiously until the full ramifications of their effect on lifetime productivity of the animal are known. Therefore, progress in the long-term levels of production will probably continue to be made in small increments rather than in quantum leaps.

livestock protection

RESISTANCE OF CATTLE BREEDS TO BLACK-FLY ATTACK

J. A. Shemanchuk

Long-haired cattle breeds showed resistance to black-fly attacks in central Alberta, and should be considered by producers in black-fly infested areas of the province.

The use of cattle as consumers of forage produced on marginal lands caused an expansion of cattle raising to central and northern Alberta and Saskatchewan. However, a limiting factor to this expansion has been the swarms of black flies that attack cattle, causing severe pain and annoyance, and injecting toxins that can cause death.

The ideal method of controlling black flies is to kill the larvae in their breeding sites in rivers and streams. Control of black flies at the breeding sites is effective but it is expensive and controversial because of environmental concerns. Furthermore, it is not always possible to achieve complete control in the numerous streams that produce black flies. Thus, other protective measures are often required.

The selection of cattle breeds resistant to black fly attack was investigated at the Lethbridge Research Station as one management practice that could be incorporated into cattle production in black fly-infested areas. This study was conducted in central Alberta where the black fly Simulium arcticum breeds in the Athabasca River and is a serious pest to cattle. Yearling Hereford, Angus, Galloway, Highland, Holstein, Ayrshire, Charolais, and Highland-Shorthorn cross steers paired to uniformity in weight and temperament were compared to detect differences in tolerance to black fly attack.

Results from this comparison indicated that Highland, Highland-Shorthorn crosses and Galloway breeds received significantly fewer bites from black flies than Hereford, Angus, Charolais, Ayrshire and Holstein steers. The long denser haircoat on the Highland, Highland-Shorthorn crosses and Galloway steers is believed to be the barrier that prevented many black flies from feeding on the animals. The use of long-haired breeds in black-fly infested areas is particularly appropriate to beef production systems and should be considered as a component of integrated management in areas where black flies are a pest all spring and summer and use of a larvicide is too expensive or not always completely effective.

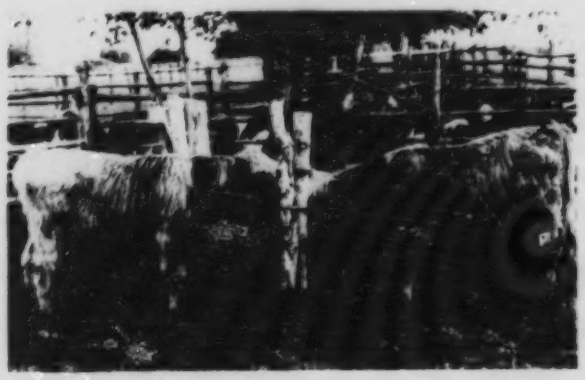


Fig. 1. Purebred Highland yearling steers with long, shaggy, dense haircoat.

Fig. 2. Highland-Shorthorn cross (Highland female X Polled Shorthorn male) yearling steers with shorter haircoat than purebred Highland, but dense enough to reduce bites from black flies. These crosses lacked horns, a desirable characteristic in beef cattle.

MODEL TO PREDICT EGG DEVELOPMENT OF A BLACK-FLY SPECIES

J. L. Shipp and G. H. Whitfield

A mathematical model was developed to predict egg development and hatch of Simulium arcticum under river conditions. Use of this model will improve the timing of insecticide treatments for the Athabasca River.

The S. arcticum sibling that breeds in the Athabasca River is a major pest of cattle in central Alberta. Methoxychlor is injected into the Athabasca River twice each season to control larvae at the major breeding sites. Timing of the methoxychlor applications is based upon the larval population level as determined from an annual monitoring program that is conducted from late April to the end of August.

Little information is known about the embryonic development and hatching of black-fly eggs. At the Research Station, a study was conducted to determine the effect of temperature on egg development and hatch of S. arcticum. This information will be used to improve the timing of larvicide treatments to the Athabasca River.

In late July and August of 1984 and 1985, gravid S. arcticum were collected over the Athabasca River using an insect sweep net. The females were transported to the laboratory where individual flies were placed into separate quadrants of covered petri plates that were half-filled with distilled water. All petri plates were maintained at 19°C and a photoperiod of 14 h L:10 h D, and were examined daily for the presence of eggs. After egg laying, the adult flies were removed and the individual batches of eggs were placed in the dark because eggs laid in the Athabasca River are not exposed to light.

Since the adult flies were collected late in the season, all egg batches were in diapause. A 71-day period at 0.5°C was found adequate for termination of diapause and longer cold periods did not increase the percent egg hatch. Between 9 and 12 egg batches were each held at 0.5°C for 71 days and then placed at constant temperatures of 3, 5, 8, 12, 18, and 20°C. All eggs were examined daily to record the stage of embryonic development and date of hatch.

Mean survival of eggs was determined for the different temperatures. The data were then fitted to a 6-parameter model to obtain the predicted values of the temperature-dependent development curve. Least-squares regression analysis was used to determine the degree-days required for development of 50 and 90% hatch.

Percent egg hatch was high at all constant temperatures tested and there was no significant difference among any of the treatments (Table 1). Egg development was almost linear for temperatures of 3-18°C and decreased rapidly after optimum development occurred at 18°C (Fig. 1). The 6-parameter model provided the best fit of predicted to observed values (R^2 = 0.99). The model described embryonic development and hatch of the egg stage over the complete range of constant temperatures tested. The linear regression equation ($Y = 0.0061X - 0.0098$; $R^2 = 0.89$) described the relationship between temperature (X) and the rate of development (Y) for 50% hatch. At a base temperature (t ± SE) of 1.6 ± 0.16°C, 163.7 ± 5.1 degree-days are required for 50% development of the egg stage. For 90% completion of development at the same base temperature, 212.8 ± 23.99 degree-days are needed and the regression equation is $Y = 0.0047X - 0.0047$ ($R^2 = 0.67$).

The degree-day estimates for 50 and 90% completion of egg hatch compared favorably with reports on egg hatch and larval development of the S. arcticum complex in the Athabasca River. The present study is the first report on egg development for S. arcticum at various temperatures and the use of a mathematical model for the prediction of egg development for black flies.

Table 1. Mean number of days and range for 50 and 90% hatch of eggs of S. arcticum exposed to constant temperatures after being held at 0.5°C for 71 days.

Temp. (°C)	No. of viable eggs	No. of hatched eggs (%)[1]	Days to hatch 50% Mean	50% Range	90% Mean	90% Range
3	471	410 (87.0)	83.6	75-92	92.5	82-99
5	593	460 (77.6)	47.8	40-51	66.6	51-92
8	722	655 (89.9)	25.6	22-33	35.4	23-54
12	546	410 (75.0)	18.8	16-22	28.5	19-49
18	732	557 (75.9)	9.5	9-11	13.0	10-27
20	542	378 (69.7)	10.0	8-14	17.3	9-43

[1]Means were not significantly different ($P<0.05$).

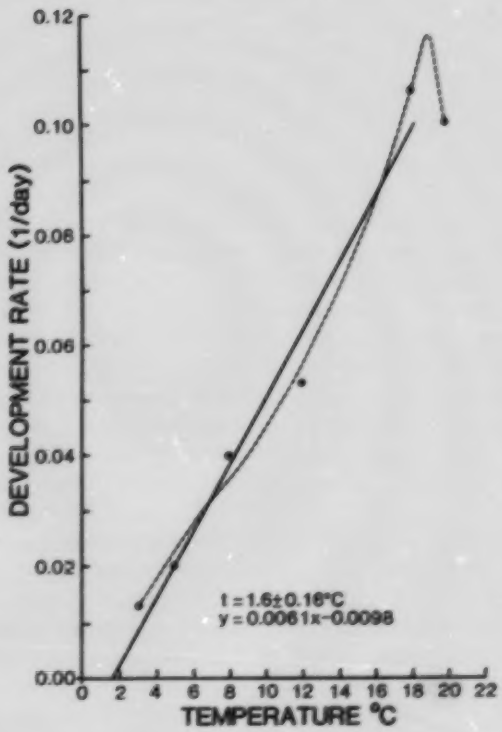


Fig. 1. Rate of egg development of S. arcticum (IIS-10.11) vs. temperature, fitted to a 6-parameter model (----), and determination of base temperature by the x-intercept method (____).

MOUTHPARTS OF TWO SIBLING BLACK-FLY SPECIES OF SIMULIUM ARCTICUM

J. L. Shipp and E. G. Kokko

Bloodsucking mouthparts were found on both Simulium arcticum (IIS-10.11) and (IIL-3). The hypothesis that the (IIL-3) cytotype is not a problem to cattle in southern Alberta because this sibling has non-bloodsucking mouthparts is not true.

Simulium arcticum consists of a complex of six sibling cytotypes in Alberta. The (IIS-10.11) cytotype is the pest sibling in the central area of the province. In southern Alberta, the (IIL-3) cytotype is widely distributed and abundant, but there have been no reports of black-fly attacks on cattle in this region. Several hypotheses have been put forth to explain why the S. arcticum complex is only a pest problem in central Alberta. One such hypothesis speculates that the (IIS-10.11) cytotype has bloodsucking mouthparts but the (IIL-3) sibling does not. In some black-fly species, the protein from a blood meal is used for egg development whereas other species carry over protein reserves from the immature stages and do not require a blood meal.

Adult females of (IIS-10.11) and (IIL-3) were examined using scanning electron and light microscopes to determine if there was any difference in the shape and structure of their mouthparts. Emphasis was placed on the mandibles and maxillary laciniae because these mouthparts are the most important for blood feeding. The (IIS-10.11) specimens were obtained from the Athabasca River downriver from the town of Athabasca. The (IIL-3) cytotypes were collected from the Oldman River in the Rocky Mountains and from the Crowsnest River in the foothills.

Similar bloodsucking mouthparts were found for both (IIL-10.11) and (IIL-3) cytotypes (Fig. 1). The shape and structure of the mouthparts were identical for both siblings. Mandibles consisted of flat overlapping plates of sclerotized cuticle that were ovate-shaped with a point at the tip. The perimeter of the mandible had a fine serrated edge. This shape and structure are suited for making an incision in the skin and lacerating the blood capillaries to form a pool of blood. The shape of the laciniae was spear-like with a row of backward-pointing teeth along the edge of a triangular-shaped head. The proximal half of the laciniae was smooth with no teeth. The tapered shape of the head with backward-pointing teeth is very effective for forcing the mouthparts deeper into the wound and helping the fly to hold its mouthparts in the wound.

The teeth on the laciniae were much larger than the serrated edges of the mandibles. Examination of the laciniae of 20 specimens of each cytotype showed that the two siblings had a mean of 26 teeth per lacinia.

The mouthparts of both S. arcticum (IIS-10.11) and (IIL-3) are well suited for blood feeding. The hypothesis that (IIL-3) is not a problem to livestock in southern Alberta because this sibling has non-bloodsucking mouthparts is not true. Other hypotheses such as the effect of climate on the survival and behavior of (IIL-3) need to be investigated.

Fig. 1. SEM micrograph of mouthparts of S. arcticum (IIL-3) showing the labrum (Lr), mandibles (M), labellum (Lm), maxillary laciniae (M1) and hypopharynx (H), x400. Inset shows the teeth of the lacina, x1900.

IDENTIFICATION AND DETERMINATION OF SOME IN VITRO METABOLITES OF DEET INSECT REPELLENT

W. G. Taylor

Five new metabolites of this insect repellent have been identified in extracts from rat liver microsomal enzymes. An analytical method, based on high resolution gas chromatography, was developed to determine these degradation products.

At present, the most popular chemical for repelling insects is N, N-diethyl-meta-toluamide, more commonly known as deet. This organic compound is used extensively in various sprays and liquids to protect man from biting flies and mosquitoes. Interest has recently increased in the experimental use of deet as a possible alternative to registered insecticides for the protection of livestock from biting insect pests. This insect repellent is currently registered for use on horses.

Despite its widespread use, little is known about the fate of deet after it is in contact with the body. A few experiments with laboratory animals have shown that some of this insect repellent is absorbed through the skin and subsequently eliminated from the body,

primarily in the urine. Even less information is available on the biochemical pathways that might account for the initial degradation of deet in the body and ultimately help to explain how this chemical is eliminated from mammalian tissues.

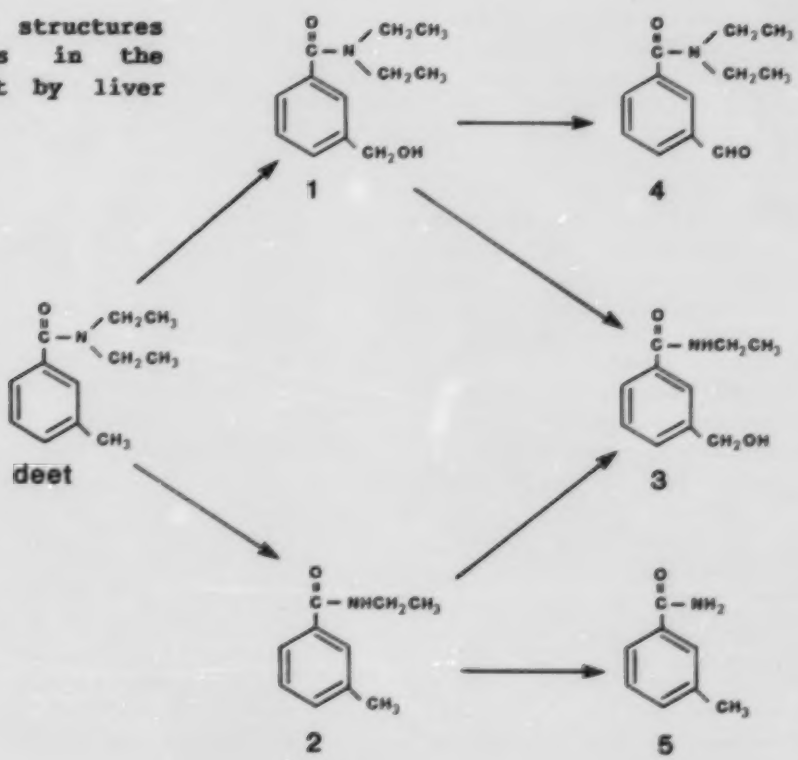
To investigate the initial metabolism of deet in a mammalian system, microsomal oxygenase enzymes isolated from the liver of male Wistar rats were employed. These enzymes, in the presence of air and biochemical cofactors, are capable of degrading various chemicals by catalyzing the addition of oxygen to one or more sites on the molecule. Thus, a variety of oxidized metabolites may be formed.

Incubation of deet (200 micromolar concentration) with suspensions of these microsomal enzymes (5 mg of protein) was carried out at 37°C and in pH 8 Tris-HCl buffer. Products from the reaction were isolated by extraction with the solvent methyl tert-butyl ether. To identify the metabolites in the extracts, the components were first separated by high resolution gas chromatography and the mass spectrum of each metabolite was obtained. This technique of combined gas chromatography-mass spectrometry led to the identification of five metabolites of deet.

Formation of two major metabolites, N,N-diethyl-m-hydroxymethylbenzamide (1) and N-ethyl-m-toluamide (2), was logical because the alcohol (1) arises from addition of oxygen to a reactive benzylic carbon atom whereas 2 results from loss of an ethyl group, which is a common metabolic process. The three minor metabolites, N-ethyl-m-hydroxy-methyl-benzamide (3), N,N-diethyl-m-formyl-benzamide (4) and m-toluamide (5), were formed by further oxidations of the major metabolites (Fig. 1).

It was also desirable to quantitatively determine these metabolites of deet in the biological extracts. This was accomplished by high resolution gas chromatography, using pure reference samples of 1 and 2 and an internal standard of N,N-dipropyl-m-toluamide (IS). By using a capillary column of DB-1 and a detector with selectivity for nitrogen atoms, the metabolites of deet were readily separated and detected (Fig. 2). Under optimum incubation and extraction conditions, it was calculated that 45.2% of the deet was converted to 1 and 23.8% to 2. The three minor metabolites combined accounted for

Fig. 1. Chemical structures depicting pathways in the metabolism of deet by liver microsomes.



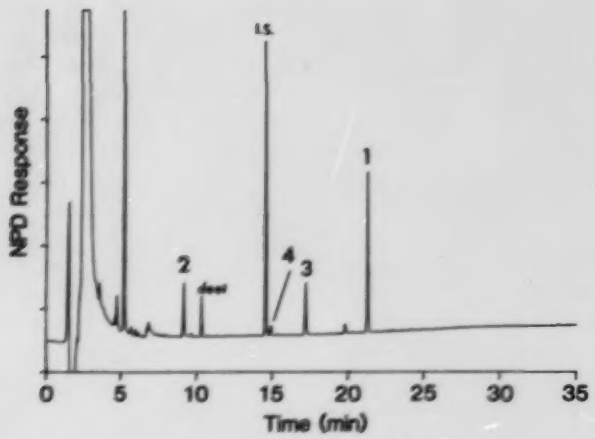
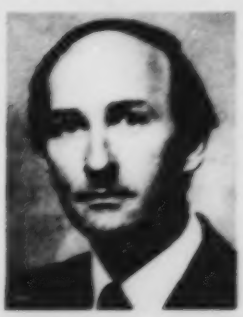


Fig. 2. Capillary gas chromatogram of an extract from the metabolism of deet by rat liver microsomal enzymes.

approximately 10% of the dose whereas 6% of the original deet was not metabolized. The various unlabelled peaks in Fig. 1 originate from endogenous components in the extracts. These compounds interfered with the determination of 5 so a different capillary column was used for the detection of this metabolite by gas chromatography.

Utilization of this in vitro technique provides good insight into the metabolites of deet that might be formed and excreted in animals.

INHIBITION OF THE BOVINE INFLAMMATORY RESPONSE BY WARBLE GRUB INFESTATIONS



R. W. Baron

The influence of enzymes secreted by warble grub larvae on the inflammatory system of cattle undergoing their first infestation was studied. Two enzymes, Hypodermin A and B, secreted by warble grub larvae were found to inhibit a protein complex that controls the initiation of the inflammatory response in naive cattle. As a result, grub survival in young animals is enhanced.

Cattle develop resistance to warble grubs (Hypoderma lineatum) after repeated exposure to infestation. This acquired resistance is known to be very important in controlling grub populations and has been shown to be dependent upon the number of previous exposures and the number of larvae invading the host.

Acquired resistance to grubs has an immunological basis with strong dependence on cell-mediated immunity. Research has demonstrated that previously infested cattle respond strongly to antigen and T-cell mitogen stimulation upon reinfestation and successfully eliminate most of their grubs. On the other hand, naive calves only respond to antigen and mitogens at the end of their primary infestation and are not successful in combatting the later grub infestations. These observations suggest that acquired resistance in young cattle is either slow to develop or subject to immunosuppression.

Parasite-specific immunosuppression is prevalent in many parasitic infestations, and parasite products and secretions are known to have a suppressive effect on the immune response. It has been suggested that the larval proteinases used by warble grubs in migration through host tissue could prevent host inflammation and thus enhance survival of grub larvae. Three enzymes--Hypodermin A, B, and C--have been identified in warble grubs as serine proteinases. Recently, it has

been shown that in naive cattle these larval enzymes, Hypodermin A and B, inhibit a series of thermolabile enzymes which control initiation of the inflammatory response. This allows the parasite to escape an early host defense reaction. To test this theory a study was conducted on the ability of warble grub larval proteinases to inactivate purified bovine C3, a protein involved in activation of the inflammatory response.

Bovine C3 was isolated from freshly drawn plasma obtained from young Charolais heifers that had not been exposed to warble infestation. A combination of anion and cation exchange chromatography followed by gel filtration was used to obtain pure C3. The three enzymes, Hypodermin A, B, and C, used by first-instar larvae in migration were isolated using ion-exchange chromatography. Specific antibodies to C3 were also required for this study. Therefore, a polyclonal antiserum and several monoclonal antisera were raised by immunization with purified C3. Subsequently, the degradation of bovine C3 by warble grub larval enzymes was studied using an immunoblotting technique after in vitro incubation of appropriate concentrations of the enzymes and bovine C3.

Proteinases isolated from larvae had a profound effect on bovine C3. Incubation of C3 with a crude larval extract containing all three enzymes led to the degradation of the alpha chain of C3 when used at a concentration of 50 µg/ml (Fig. 1a). Some activity was apparent even at a concentration of 10 µg/ml. Hypodermin A (Fig. 1b) also degraded the C3 molecule. However, Hypodermin B was the most effective since both the alpha and beta chain (Fig. 1c) were cleaved. Hypodermin C did not affect bovine C3.

These results clearly demonstrate that larval warble grub enzymes can break down bovine C3. Each larva may produce 10-20 µg of enzyme daily, which under normal infestation levels is sufficient to render the inflammatory response ineffective and could thus modulate the early host defense mechanisms of a naive bovine during its primary infestation. In previous work it was shown that the cellular response to infestation in naive animals was not stimulated until the end of the infestation. Thus, there

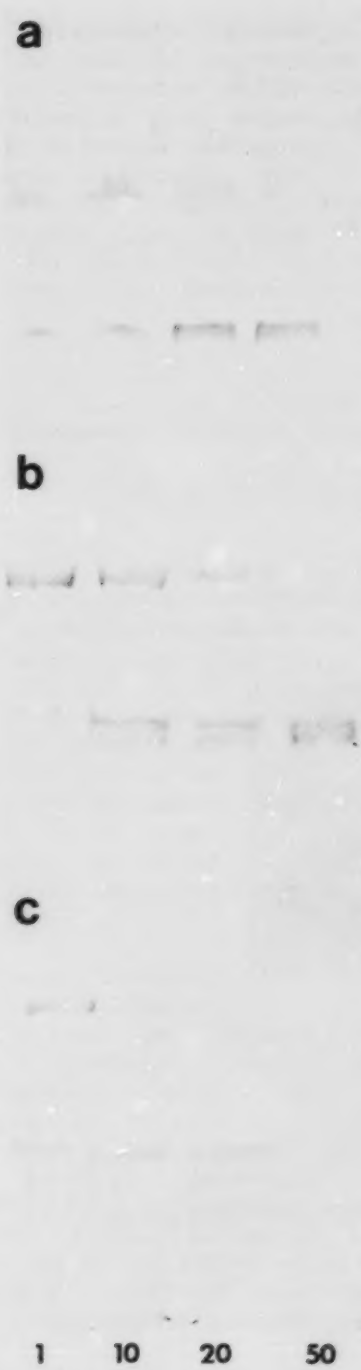
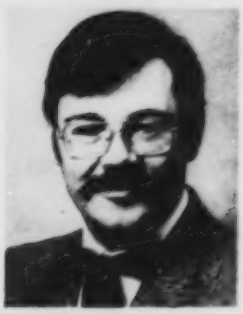


Fig. 1. Degradation of bovine C3 analysed by SDS polyacrylamide gel electrophoresis followed by western immunoblotting. (a) bovine C3 incubated with 1,10,20 and 50 µg/ml of crude warble grub extract. (b) bovine C3 incubated with 1,10,20 and 50 µg/mol of Hypodermin A. (c) bovine C3 incubated with 1,10,20 and 50 µg/ml of Hypodermin B.

may be a general suppression of host defense mechanisms in the naive host. This would allow successful completion of larval warble grub infestations and serve as a perpetual source of infectious material for future generations. Development of a safe, effective vaccine for grub control may, therefore, be dependent on overcoming the immuno-suppression induced by larval-derived enzymes.

CELLULAR IMMUNITY IN WARBLE GRUB INFESTATIONS: EOSINOPHIL RESPONSES TO INVADING AND MIGRATING LARVAE



D. D. Colwell

This study demonstrates that eosinophils, a type of white blood cell, are involved in the host immune response to invading cattle grubs and opens the way for studies which will clarify the role of these cells in grub mortality. Understanding of the eosinophil impact on these parasites will aid the development of an effective anti-grub vaccine.

Systemic insecticides currently provide excellent control of warble grubs, Hypoderma spp. However, complete reliance on these compounds is undesirable for several reasons. Side effects of insecticidal treatments to livestock increase producer costs, insecticide residues in foodstuffs are a matter of increasing concern, and use of systemic insecticides slows the onset of host resistance to future infestations of grubs, thereby requiring continued use of the insecticides. At the Lethbridge Research Station studies of the host-parasite interactions between cattle immune systems and the invading warble grubs are part of an effort to develop an effective vaccine which will aid in reducing the livestock producers' dependency on systemic insecticides.

In many host-parasite systems the host response to tissue-invading parasites is characterized by a dramatic increase in the number of eosinophils present in the circulating blood and in tissues around the parasite. These white blood cells have the ability to recognize the invader, attach to its surface, and release toxins which can ultimately result in death of the parasite. Previous work on cattle has shown that resistance to grubs is slow to develop and one or more infestations are required for this resistance to become effective. A single vaccination with a crude grub antigen prepared from first-instar larvae can produce a significant level of immunity in cattle. However, the vaccine must be improved if it is to induce a level of protection similar to that produced by natural infestation with the parasite.

Earlier work at Lethbridge suggested that cattle previously infested with grubs had elevated eosinophil levels in response to a second infestation. Thus, because eosinophils have the ability to act as effector cells in host responses to parasites and because they are known to be intimately connected with the host's cellular immune system, a study of

eosinophil responses in cattle infested with warble grubs was undertaken. The aim of this initial study was to examine the systemic eosinophil responses to warble grub infestation in previously infested and uninfested cattle in order to establish whether there is sufficient evidence to warrant further study of the eosinophil role as an effector of the cattle response to grubs.

Circulating eosinophil levels were monitored weekly in the blood of cattle that had received several previous infestations of grubs and were known to have significant resistance. Eosinophil levels were monitored similarly in cattle known to have had no previous grub infestations. The previously infested cattle (PI) received a challenge infestation of approximately 100 H. lineatum larvae followed 5 weeks later by a concomitant infestation with approximately 100 H. bovis larvae. Previously uninfested cattle (PU) received a primary infestation with 100 H. lineatum larvae followed 9 weeks later by a concomitant infestation of another 100 larvae. Control groups of similar history but not infested with warble grubs during this experiment were maintained and monitored as were the two infested groups.

A substantial rise in the circulating eosinophil levels in PI cattle was observed beginning in the second week after the challenge infestation (Fig. 1). Maximum levels were reached by the third week with a decline to near pre-exposure levels by the fourth week. Concomitant infestation of the PI cattle also resulted in a peak of eosinophil activity, which began in the second week (Fig. 1). Eosinophil levels in the PI cattle which did not undergo a challenge infestation remained unchanged during the course of the experiment. Survival of grubs in the PI cattle, as measured by the number that reached the back to form "warbles", was 3.4%.

Circulating eosinophil levels in PU cattle remained unaffected by the initial infestation with warble grub larvae (Fig. 2). However, when exposed to the concomitant infestation 9 weeks later there was a rapid and substantial increase in the circulating eosinophil levels. Response of the PU cattle to the concomitant infestation peaked by the second week with a decline to pre-exposure levels by the fourth week. There was no lag in development of the eosinophil increase as noted in the PI cattle. Survival of warble grubs from the primary infestation in PU animals was 43%.

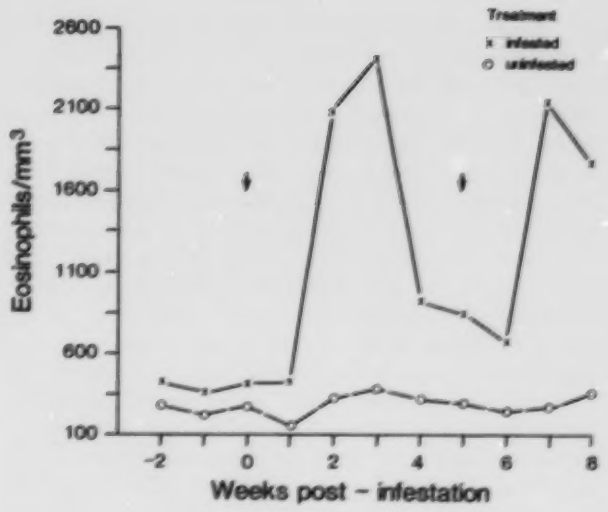


Fig. 1. Circulating eosinophil response in previously infested cattle reinfested with cattle grubs. Arrows indicate dates of infestation.

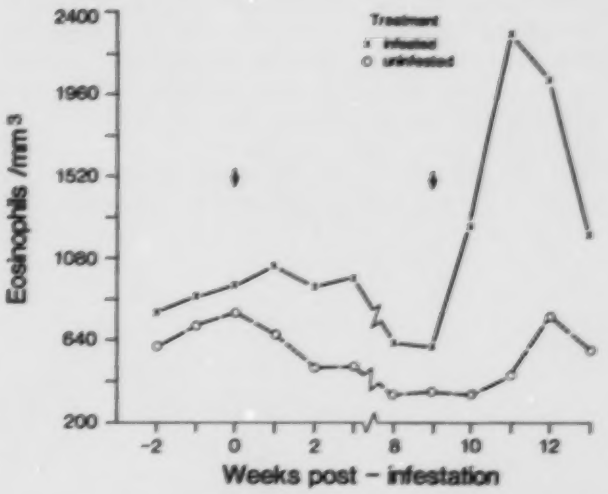


Fig. 2. Circulating eosiniphil response in previously uninfested cattle infested with cattle grubs. Arrows indicate dates of infestation.

Eosinophils are clearly part of the host response to invasion by warble grub larvae. In PI cattle the lag that occurs between invasion and elevation of the circulating eosinophil levels reflects the time required by the host to recognize the larvae and start the processes that lead to massive production of new eosinophils. In PU cattle the lack of an eosinophil response to a primary infestation confirms previous observations that warble grub larvae are able to suppress both the developing immune response and the non-specific inflammatory responses through enzymatic alteration of vital elements of both systems. The rapid eosinophil response to concomitant infestation in PU cattle suggests that the host system is able to overcome initial suppression and mount a substantial response which would be expected to have impact on late-arriving larvae.

Information from this study opens the way for further examination of the interaction between eosinophils and invading warble grubs. If it can be demonstrated that eosinophils are active in killing warble grub larvae migrating within the host, then development of an effective vaccine can be enhanced through use of mediators which will heighten the host's parasite-specific eosinophil response.

crop production

BARRIER ALFALFA: A NEW DISEASE-RESISTANT VARIETY

M. R. Hanna and H. C. Huang

Verticillium wilt disease has been damaging alfalfa stands in some areas of southern Alberta and the southern and central interior of British Columbia since the late 1970's. Barrier, developed at the Lethbridge Research Station and licensed in 1986, is the first Canadian variety of alfalfa with resistance to this disease. It produces good forage and seed yields and is resistant to bacterial wilt disease. Certified seed of the new variety will be available to forage producers starting in 1988.

Verticillium wilt (VW), caused by the fungus Verticillium albo-atrum, has long been regarded as the most serious disease of alfalfa in western Europe. In 1976, it was detected in the northwestern United States and since then has spread rapidly to many of the most important alfalfa-growing areas of both Canada and the United States. The effects of VW have been particularly severe in the southern interior valleys of British Columbia and in some of the irrigated districts in southern Alberta.

In response to the threat posed by VW, an alfalfa breeding program was started at the Lethbridge Research Station in 1979. Barrier, the first Canadian variety with resistance to VW, was granted licence No. 2615 on February 10, 1986.

Origin

Barrier is a 76-clone synthetic variety derived from hybridization among a number of European and North American varieties. The European varieties are valuable sources of resistance to VW but are almost all highly susceptible to bacterial wilt (BW), another very destructive disease of alfalfa. The varieties from Europe also lack winterhardiness for most areas of Canada with the exception of parts of British Columbia. The North American varieties have good resistance to BW and although most are susceptible to VW they are otherwise well adapted to the areas in western Canada that are threatened by VW.

Four European varieties (Vertus and Sverre from Sweden, Maris Kabul from the U.K., Euver from France) and five North American varieties (Trek, Beaver, and Algonquin from Canada; Vernal and Thor from the United States) are involved in the parentage of the 76 plants that form the basis of Barrier. These 76 plants were selected for resistance to both VW and BW in growth room and greenhouse tests at Lethbridge. Their disease resistance and agronomic performance in the field were then assessed in a breeding nursery at Creston, British Columbia.

After the 76 selected plants had been intercrossed in the greenhouse, the strain was further increased under isolation in the field to provide sufficient seed for forage yield trials and other tests across western Canada.

Characteristics and Performance

Barrier has consistently shown a higher level of VW resistance than other European or North American varieties. In 8 growth room and greenhouse trials conducted at Lethbridge and Guelph, Barrier contained 56% resistant plants, compared with 35% in Vertus, the resistant European check. Trumpetor, the most widely used of the resistant U.S. varieties, averaged 23% resistant plants. Anchor, the susceptible check variety in all Lethbridge tests, averaged 10% resistant plants. Barrier is also resistant to BW. It averaged 71% BW-resistant plants in two greenhouse trials, being equivalent to Anchor (75%) or Beaver (66%). The VW-resistant varieties Trumpetor and Vertus, which were included in one of the two trials, had only 44% and 15% BW-resistant plants, respectively.

The forage yield of Barrier has been excellent in the areas of British Columbia and Alberta where VW and BW are prevalent. At Creston, the first yield trial in which Barrier was entered was seeded in 1982; the VW-resistant varieties WL 316, Apollo II, Trumpetor, and Vertus were also established in this

trial, along with the VW-susceptible variety Anchor (Table 1). There was very little disease evident in this trial during the first two harvest years, but damage from VW was severe in 1985 and 1986. Although Barrier's yield was somewhat lower than that of the other varieties in 1983 and 1984, it was the highest-yielding variety in 1985 and 1986. The yields of the other five varieties ranged from about 10 to 80% lower than that of Barrier in 1986. BW was also recorded in the test, and stand losses from VW, BW, and/or winterkilling could not be clearly separated. However, it seems evident that the high level of disease resistance in Barrier has played a major role in the ability of the variety to persist and maintain a productive stand.

Barrier has also yielded well in trials conducted at the Lethbridge Research Station since 1982 (Table 2). Over 7 test-years, Barrier has yielded 3 to 6% higher than WL 316, Apollo II, Trumpetor, and Anchor, and 12% higher than Vertus. The low yield of Vertus appears to be due to a combination of its susceptibility to BW and its lack of winterhardiness. VW has not yet been an obvious factor in the Lethbridge trials, although it is becoming widespread in irrigated fields surrounding the Research Station. A concerted effort has been made in recent years to keep the disease out of the experimental plot areas at the Station. However, symptoms of VW were noted in susceptible varieties in several yield trials at the Station in 1986.

Certified seed of Barrier should become available for the establishment of forage stands starting in 1988. SeCan Association is responsible for the distribution and seed increase of the new variety.

Table 1. Relative forage yields of alfalfa varieties in a trial established in 1982 at Creston, British Columbia.

Variety	Disease resistance[1]		Forage yield (as % of Barrier)[2]				
	VW	BW	1983	1984	1985	1986	Avg
Barrier	R	R	100	100	100	100	100
WL 316	MR	MR	109	117	99	87	102
Apollo II	MR	R	103	108	96	90	99
Trumpetor	MR	MR	105	111	90	59	90
Anchor	S	R	107	112	84	48	86
Vertus	R	S	118	114	61	19	76
Yield of Barrier (kg/ha)			10110	8010	11810	9890	9960

[1] R = resistant, MR = moderately resistant, S = susceptible.
[2] 3 cuts harvested each year.

Table 2. Relative forage yields of alfalfa varieties in trials established in 1982 and 1983 at Lethbridge, Alberta.

Variety	Forage yield (as % of Barrier)		
	1982 test 4-year avg	1983 test 3-year avg	Avg - all test years
Barrier	100	100	100
WL 316	90	98	94
Apollo II	93	99	96
Trumpetor	93	96	94
Anchor	99	95	97
Vertus	79	97	88
Yield of Barrier (kg/ha)	10550	13680	11890

LICENSING OF FIRST CANADIAN SAFFLOWER

H.-H. Mündel and H. C. Huang

In April, 1985 the first Canadian safflower variety, 'Saffire', was licensed as a result of cooperative efforts by Alberta Agriculture (through a Farming for the Future project) and Agriculture Canada. This safflower variety provides an alternate cash crop that is especially suitable for the birdseed market.

The Alberta farming community seeks greater cropping diversity to improve cash flow and net income as well as to enhance agricultural production through appropriate crop rotation. Few crops can be alternated with cereals in the dryland areas of southern Alberta and the southern prairies. The thistly safflower, a drought-resistant oilseed and birdseed crop, could become a desirable alternate crop in this region. Safflower has been grown occasionally since the early 1940's. However, the safflower varieties available in the past required too long a growing season to be safely produced in most of the Canadian prairies. According to the Research Station records, a fall frost could be expected prior to maturity in 7 of 10 years.

Recent cooperative work between provincial and federal researchers has produced a safflower variety suitable for the dryland prairie regions. As starting material, a safflower bulk of mixed maturities, flower colors, and plant types, originating from India in the early 1940's, was grown in 1978. Single plants were selected for early maturity and flower color. Since 1979, funding by Farming for the Future has provided equipment and personnel assistance for the development of varieties in this crop. By 1982 the first yield tests were conducted at Lethbridge. In 1983, in cooperation with the Morden Research Station New Crops program, a prairie-wide testing program began. Data from 2 years of testing were accepted by the Canada-wide Expert Committees and Agriculture Canada's Plant Products to help launch this new crop. The Alberta Special Crop Advisory Committee supported the licensing of this variety.

Yield levels of Saffire compared well with the standard U.S. varieties, averaging 9% above S-208 and equalling Hartman (over 22 location-years). Year-to-year variations in maturity for any given safflower variety are tremendous. Saffire was carried under the experimental line number Lesaf 34C-00. The longest duration for maturity recorded for Saffire was 141 days in 1981. With late April to early May planting, it could mature by mid-September, when the first killing frosts could be expected. By contrast, over 150 days were recorded for standard U.S. varieties in the same years (Table 1). Safflower seedlings can withstand spring frosts down to -10°C.

Aside from maturity and yield, a major concern was the fungal disease Sclerotinia head rot. With moist soil conditions from flowering on, this disease can cause devastating results where seeds do not fill and heads are blown off. It is the same organism that attacks other oilseed crops such as canola, mustard and sunflower, and pulse crops such as field beans and lentils. Sclerotinia screening nurseries were established and conditions were manipulated to maximize infection. Thus it was possible to consistently, from year to year, screen for high levels of resistance during the development of Saffire. These screening tests showed that Saffire is more resistant to Sclerotinia head rot than the standard commercial U.S. cultivar, S-208, and other cultivars and experimental lines (Mündel et al. 1985a, 1985b).

During 1983 to 1986, Alberta Agriculture coordinated farm-scale testing of Saffire. The tests started with 0.4-ha plots, increased to 4-ha then 16-ha fields, and in 1986 were conducted in fields up to 100 ha in size. The crop was seeded with a regular grain drill, and straight combining was no problem, once the combine was properly adjusted.

Table 1. Comparison of maturity of 'Saffire' and standard U.S. safflower cultivars.

Entry	Days to maturity (for years indicated)						
	1980	1981	1982	1983	1984	1985	1986
Saffire	135	141	138	111	112	108	114
S-208	141	152	155	120	119	117	125
Hartman		151	154	121	120	117	126
Locations	2	2	1	8	8	2	2

After the testing and selecting stage was complete, the Agriculture Canada Regina Research Station agreed to handle the Breeder Seed production and the Secan Association arranged to produce pedigreed seed. With 38 ha of pedigreed seed produced in 1986, certified seed for around 2000 ha should be available by 1987. A number of firms are now actively contracting with farmers to grow safflower. Saffire has a maturity level early enough to make its production safe over a substantial area of the Prairies.

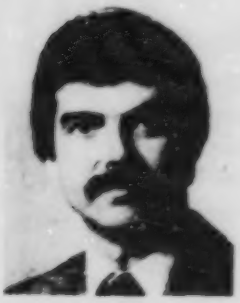
The bright whitish seed of Saffire makes it suitable for the birdseed market. At present this market pays the growers several cents a pound above the oilseed market. The oil level of Saffire is low. Over the years, cooperators in Manitoba, at the Grain Research Laboratory and the Morden Research Station, as well as the Seedtec Company in California, analyzed the oil levels. Now, with suitable equipment at Lethbridge, large numbers of samples required in a breeding program will be screened to eventually produce a high oil, early maturing, sclerotinia-resistant safflower variety.

Mündel, H.-H.; H.C. Huang; G.C. Kozub. 1985a. Sclerotinia head rot in safflower: assessment of resistance and effects on yield and oil content. Can. J. Plant Sci. 65:259-265.

Mündel, H.-H.; H.C. Huang; L.D. Burch; F. Kiehn. 1985b. Saffire safflower. Can. J. Plant Sci. 65:1079-1081.

WILD MUSTARD AND LAMBSQUARTERS REDUCE GROWTH AND YIELD OF CANOLA

R. E. Blackshaw



Relatively low infestation densities of wild mustard and lambsquarters cause serious yield losses in canola. Farmers having canola crops infested with more than 20 plants/m^2 of either weed should realize an economic return by controlling them.

Canadian farmers spend approximately $244 million annually on herbicides for the control of weeds in crops (Eue 1986). Information on crop yield reductions associated with varying weed densities allows comparison of the potential monetary gains achieved by controlling those weeds with the cost of applying herbicides for their control. Such information aids farmers in their decision to apply a herbicide.

In Canada, the estimated annual losses caused by weeds in canola is $107 million (Chandler et al. 1984). In light of this, surpisingly few weed interference studies have been conducted in canola. Although wild mustard and lambsquarters are commonly occurring weeds in canola grown in Canada, there are no reports in the literature on the ability of either of these weeds to interfere with canola. Experiments were conducted at the University of Guelph to quantify the responsiveness of canola dry weight and grain yield to varying infestation densities of wild mustard and/or lambsquarters.

Both wild mustard and lambsquarters interfered with canola early in the growing season. By late June of 1983 and mid-June of 1984, 20 weeds/m^2 of either species caused a significant reduction in the dry weight of canola (Table 1), indicating that interference had occurred prior to that time. This density of wild mustard continued to cause a significant decrease in canola dry weight for the entire growing season of both years. An infestation density of 20 lambsquarters/m^2 was sufficient to cause a significant decrease in canola dry weight throughout 1983 but not 1984.

At the weed densities recorded in this study, wild mustard caused significantly greater reductions in canola dry weight than did lambsquarters throughout both years (Table 1). Treatments including both weed species caused canola dry weight reductions intermediate to those caused by either weed alone at most sample dates.

A density of 20 plants/m^2 of wild mustard, lambsquarters, or the two weed species combined significantly reduced the seed yield of canola in both years (Table 2). Increasing the density of wild mustard from 20 to 80 plants/m^2 resulted in a further significant reduction in canola yield in both years. In contrast, a similar increase in the density of lambsquarters did not cause a further reduction in canola yield in either year.

Wild mustard caused greater reductions in canola grain yield than did lambsquarters in both 1983 and 1984 (Table 2). With weed densities of this study, canola yield reductions ranged from 20-77% with wild mustard but only 20-25% with lambsquarters. This may be partially due to the similar growth habit and life cycle of wild mustard and canola. In this study, wild mustard and canola were observed to emerge, flower, and mature at similar dates while lambsquarters emerged 7-10 days later than the other two species and continued to lag behind in development by this amount throughout the growing season.

The lowest canola yield loss in this study was 19%. With the yield of weed-free canola in this study and the current selling price of canola, this represents a monetary loss of $50 to $60 per hectare. If the cost of controlling these weeds is less than this value, then farmers should realize an economic return by using a herbicide for their control. An added benefit of controlling weeds is the prevention of weed seed production.

Table 1. Percent reduction in dry weight of canola due to varying densities of wild mustard (WM) and/or lambsquarters (LQ).

Weed density (plants/m^2)	1983		1984		
	June 28	August 10	June 18	July 16	August 1
20 WM	35	27	39	55	42
40 WM	66	42	47	50	45
80 WM	75	72	53	55	61
20 LQ	33	19	18	20	17
40 LQ	32	26	23	29	34
80 LQ	49	20	18	21	31
10 WM + 10 LQ	38	26	14	19	31
20 WM + 20 LQ	47	39	36	36	41
40 WM + 40 LQ	64	59	51	54	45
	Single d.f. contrasts				
Effect of WM density					
0 vs. 20	**	**	**	**	**
20 vs. 80	**	**	**	NS	NS
Effect of LQ density					
0 vs. 20	**	**	**	**	NS
20 vs. 80	NS	NS	NS	NS	NS
Effect of weed species					
WM vs. LQ	**	**	**	**	**
WM vs. WM + LQ	NS	**	**	**	**
LQ vs. WM + LQ	**	**	**	**	**

*P < 0.05, **P < 0.01, NS = not significant.

Over the weed densities of this study, wild mustard produced 5700-30,100 seeds/m^2 while lambsquarters produced 3100-63,600 seeds/m^2 (data not shown). Even if only a small percentage of these seeds were to become established seedlings in the subsequent crop, a serious weed problem would be created.

Farmers having canola crops infested with more than 20 plants/m^2 of wild mustard and/or lambsquarters should seriously consider a means for their control.

Chandler, J.M.; A.M. Hamill; A.G. Thomas. 1984. Crop losses due to weeds in Canada and the United States. Weed Science Society of America, Champaign, IL. P. 22.

Eue, L. 1986. World challenges in weed science. Weed Sci. 34: 155-160.

Table 2. Percent reduction in grain yield of canola due to varying densities of wild mustard (WM) and/or lambsquarters (LQ).

Weed density (plants/m^2)	1983	1984
20 WM	36	19
40 WM	45	41
80 WM	77	56
20 LQ	25	20
40 LQ	25	22
80 LQ	24	25
10 WM + 10 LQ	32	19
20 WM + 20 LQ	39	33
40 WM + 40 LQ	71	43
Single d.f. contrasts		
Effect of WM density		
0 vs. 20	**	**
20 vs. 80	**	**
Effect of LQ density		
0 vs. 20	**	**
20 vs. 80	NS	NS
Effect of weed species		
WM vs. LQ	**	*
WM vs. WM + LQ	NS	NS
LQ VS. WM + LQ	**	NS

*P < 0.05, **P < 0.01, NS = not significant.

RANGE FORAGE PRODUCTION OVER 50 YEARS

S. Smoliak

Range forage production determined over a 50-year period at the Onefour Research Substation near Manyberries was related to several climatic factors. Precipitation from April through July was highly correlated with range forage production and this relationship could be used to predict annual forage production by 1 August each year.

Studies on the response of mixed prairie to weather and climatic fluctuations have not concentrated on the relationship between climatic variations and range forage yields. Such relationships could provide ranchers and grazing land administrators with a method of predicting suitable stocking rates on mixed prairie rangeland. Therefore, this study was initiated to study the relationship between some climatic factors and range forage production obtained over a 50-year period at the Onefour Research Substation near Manyberries, Alberta. The basic climatic factors were precipitation, pan evaporation, temperature, hours of sunlight and wind velocity.

There were considerable fluctuations in range forage production and the measured meteorological factors from 1930 to 1983. The study period excluded 1941, 1944, 1945 and 1946, when no forage data were available. Forage yields varied from a low of 96 kg/ha in 1961 to a high of 925 kg/ha in 1942, with a mean of 388 kg/ha.

Highest precipitation amounts were recorded in 1965 for the April-July, annual, and previous year + January-July periods. The lowest amounts recorded were in 1936 for April-July and the previous year + January-July, and in 1943 for annual. Mean amounts of precipitation were 164 mm for April-July, 327 mm for the annual, and 558 mm for the previous year + January-July total. Evaporation during May through July averaged 584 mm, but ranged from a low of 322 mm in 1955 to a high of 947 mm in 1973.

Mean temperature during April-July was 12.8°C, with a low of 10.0°C in 1967 and a high of 15.4°C in 1936. Total hours of sunlight during April-July ranged from a low of 840 in 1968 to a high of 1342 in 1980, with a mean value of 1049 hrs.

Mean wind velocity during April-July over a 39-year period was 19.1 km/hr, and ranged from 15.9 km/hr in 1938 to 24.1 km/hr in 1956.

Correlations between forage production and the various meteorological measurements at selected periods showed that forage production was significantly correlated with precipitation for the months of April, May, June, and July, but a better correlation ($r = 0.74$) was obtained with the April-July total, or seasonal precipitation. Annual precipitation, when correlated with yield, also showed a correlation coefficient of 0.74, but it has no predictive value for the current summer grazing season. Seasonal precipitation therefore gives a better predictive value of the current year's forage production than the annual total and could be used more effectively in management application, especially if rangelands are grazed during the growing season. The various combinations of seasonal precipitation did not improve the relationship when correlated with forage yield.

The regression equation derived from the relationship of forage yield and April-July precipitation is

$$Y = 72.2 + 1.93X$$

where Y is the estimated yield of forage in kilograms per hectare and X is the total April-July, or seasonal, precipitation in millimeters. This equation may be used as an estimate of annual forage production as early as 1 August each year to make management adjustments in the event of drought, to devise grazing plans for fall or winter grazing, or to plan for the next year.

There was a low but significant relationship between precipitation recorded the previous year, the total previous winter snow, precipitation recorded the previous September or during the previous 2 years, and forage production. The inclusion of several monthly precipitation totals improved the above relationships greatly with the highest correlation coefficient (0.77) being obtained with the addition of April-July precipitation to the previous September total. The regression equation for this relationship was

$$Y = 36.6 + 1.87X$$

where Y is the estimated forage yield and X is the precipitation for the previous September plus the April-July total. The relationship between the previous year through July precipitation and forage yield also showed a high correlation (0.74).

Pan evaporation totals, mean temperature, and hours of sunlight were negatively correlated with forage production. The highest correlation coefficient (-0.62) was obtained between the relationship of April-July mean temperature and forage production. Wind velocity recorded during the growing season did not show any relationship to forage production.

Stepwise multiple regression analyses were conducted on yield and the monthly values of precipitation, pan evaporation, hours of sunlight, mean temperature, and average wind velocity during the growing season (April-July). The inclusion of temperature improved the relationship between precipitation and forage yield. However, the inclusion of hours of sunlight, wind velocity, or evaporation did not improve the correlation significantly. The best relationship was with

the June and July precipitation totals and the May and June temperatures, which accounted for 63% (r = 0.79) of the variation in range forage yields.

During the 50 years that forage yields were obtained, 12 years were above-average, 26 were average, and 12 were below-average. The below-average and above-average values included all yields less than 0.7 or greater than 1.3 of the long-term average, respectively. The frequency of below-average range forage production, about once in 4 years, indicates that greater attention must be given to establishing proper stocking rates to provide an adequate carry-over of forage during average years.

The yield data presented, in conjunction with meteorological records, can be used in range forage yield models to forecast range forage production and to prepare management plans during the grazing season. The data also can be utilized in the study of the feasibility of weather modifications in rangeland areas and in predicting the effectiveness of such manipulations. However, the predictive equations may be applicable only to the particular site as different range vegetation types or soils would show varied estimates of production.

LITTER REMOVAL INFLUENCES RANGELAND FORAGE PRODUCTION

W. D. Willms and S. Smoliak

Herbage yields in the Mixed Prairie decreased 57% when litter was removed during the previous dormant season. Removing litter in the Fescue Grasslands resulted in shorter but denser tillers with no subsequent effect on yield. As a result, estimates of potential carrying capacities of Mixed Prairie Grasslands, determined from grazing exclosures, need to be reduced by up to 60% to reflect the optimum. No similar adjustment is needed for estimates derived from exclosures in the Fescue Grasslands.

The effect of removing senescent forage or litter on forage production has usually been ignored since photosynthetic tissue or stored energy was not affected. However, the inability to derive a meaningful estimate of carrying capacity from exclosures on the Mixed Prairie has raised questions about the effect of protection from grazing, and the impact of removing senescent plant material, on forage yield. Since yield estimates from exclosures are commonly used to estimate the potential carrying capacity of native range, and in some areas winter grazing is commonly practiced, experiments were made to determine the effect of removing litter on forage yields from native grasslands.

Experiments were located in the Mixed Prairie at the Onefour Research Substation and in the Rough Fescue Grassland at the Stavely Research Substation. In one experiment, litter was removed prior to the growing season on one of four plots. Annual production was determined on this plot, and on one previously undisturbed plot (control), after the growing season in each of 3 years. The trial was repeated three times in both plant communities. In another experiment, senescent vegetation and litter were removed in either spring or fall from rough fescue plants. Tiller densities and plant heights and yields were measured following the growing season.

Forage yields, as a proportion of the control, decreased with each successive year of removing litter in the Mixed Prairie but remained constant at about 76% in the Fescue Grassland (Table 1). However, in the second experiment, yields of rough fescue were not affected by the removal of senescent vegetation and litter (Table 2). Plant height was reduced in relation to the severity of defoliation but tiller numbers were increased. The season of defoliation, whether in spring or fall, had no effect on plant response.

The apparent anomaly in yields from the Rough Fescue Grasslands, between the first and second experiments, seemed to result from the method in which litter was separated from current production. In the first experiment, current production in the control was determined by raking the litter out of the plot and harvesting the residual forage. This approach would overestimate yields of rough fescue because the leaf sheath, which accumulates from year to year, would be included with current production. This problem was not encountered in the second experiment, where the litter was hand-separated from current growth, nor in the Mixed Prairie site of the first experiment where the sheaths of grasses did not contribute to litter.

Litter affects forage production by modifying the plant environment. As a result, litter may either increase or decrease the production potential of a site depending on the prevailing climate and the quantity of litter that has accumulated. Where soil moisture limits plant growth, the insulating effect of litter may increase forage yields by reducing evaporation and conserving moisture. This appears to be the effect observed in the Mixed Prairie where average accumulation of litter was about 60 g/m^2.

Table 1. Herbage yields as a proportion of the control (%) in Mixed Prairie and Rough Fescue Grasslands.

No. harvests	Mixed Prairie	Fescue Grasslands
1	72	77
2	50	76
3	43	76

However, more than 800 g/m^2 of litter accumulated in the Fescue Grasslands. Lack of an increase in yield, despite the removal of this large quantity of litter, indicates that the moisture conservation effect is not important. On the other hand, large quantities of litter may inhibit production.

In the second experiment, and in other work (Willms et al. 1986), an increase in yield was observed when litter was removed in the Fescue Grassland. Although removing litter resulted in a reduction of plant height, tillering was stimulated. This effect may be produced when litter is removed and light intensity at the crown is increased.

Litter is an important component of the grassland ecosystem. Although the exact relationship between quantity of litter and insulation effect is not

Table 2. Response of rough fescue to removal of litter and senescent foliage at two heights above ground in fall or spring.

Defoliation treatment Season	Height (cm)	Plant weight (g)	Plant height (cm)	Tiller numbers/plant
Fall	5	37	35	232
Spring	5	32	38	222
Fall	15	41	51	246
Spring	15	43	50	284
Control		38	63	168

known, it is evident that litter enhances production on dry sites and, presumably, moderates the effects of drought. Consequently, grazing should be managed to ensure a significant proportion of litter in the grassland. Until more precise relationships can be developed, the grazing recommendations provided by Wroe et al. (1981) should be followed.

The effect of litter should also be considered when interpreting data from grazing exclosures. Using yield data from exclosures in the Mixed Prairie may result in overstocking by up to 60% since even moderate stocking rates will substantially reduce the litter component. Smoliak et al. (1985) reported a 40% reduction of yield in moderately grazed areas in relation to yield in exclosures.

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crop protection

A TWO-COMPARTMENT MODEL FOR BETTER PREDICTION OF PESTICIDE RESIDUES

B. D. Hill

Analysts often find that residue dissipation on crops and soils is biphasic. Immediately after spraying there is a rapid loss of residues followed by a period of slower decline. A model has been developed for this situation. The result is a more accurate prediction of residues which will help minimize the environmental impact of pesticides.

Before a new pesticide is registered for agricultural use, dissipation studies are conducted to determine how long the chemical residue will persist in crops and soils. A judgement is then made by registration authorities as to whether the residue persistence is acceptable. Often this judgement requires that projections be made from data obtained under one set of conditions to another situation where the crop, soil, rate of application, or time for dissipation are different. Such projections are facilitated by fitting a model to the original dissipation data and then calculating a summary statistic.

The first-order model $C = C_0e^{-kt}$ (where C is the residue at time t, C_0 is the initial residue, and k is the dissipation rate constant) is most often applied to residue data because (1) it is simple and readily understood, i.e., dissipation occurs at a constant rate described by the value of the rate constant k, (2) the equation for the model can be transformed into $\log C = \log C_0 - kt$ so that logC plotted against t gives a visual straight line fit of the model to the residue data, (3) a half life summary statistic, $T_{1/2}=0.693/k$, can be calculated where $T_{1/2}$ is the time for a given residue to dissipate to one-half its value.

The first-order model assumes that residue dissipation can be described as one concerted process, governed only by the rate constant k. In reality, there are several processes involved in residue dissipation. However, their effects may be additive or the data may be obtained in such a manner that the overall dissipation still appears to be first-order.

As methods have improved and more accurate estimates of residues are obtained, researchers now often find that residue dissipation deviates from first-order. Dissipation is commonly biphasic, i.e., there is an initial rapid loss of residues followed by a second phase of slower dissipation. At least two distinct processes are involved and the first-order model does not give an accurate prediction of residues.

We have developed a two-compartment model (2CM) and have applied it to biphasic residue dissipation on soil. Our 2CM (Fig. 1) predicts a fast initial dissipation due to surface losses of the deposited residue (Ks) plus some degradation of the retained residue (Kd). Then, as more residue is retained (Kr), the surface losses (Ks) stop, and the residue dissipates exclusively via the slower, retained residue, degradation route (Kd).

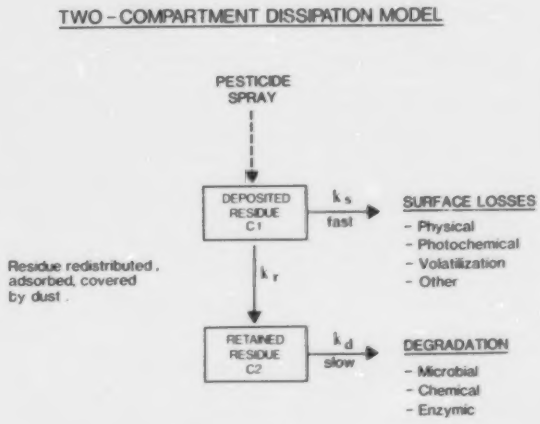

Fig. 1. Two-compartment model for residue dissipation on soil.

The equation that describes our 2CM is:

$$C = C_0 e^{-(Ks+Kr)t} + C_0 \left[\frac{Kr}{Ks+Kr-Kd}\right]\left[e^{-Kdt} - e^{-(Ks+Kr)t}\right]$$

where C is the residue at time t, C_0 is the initial deposited residue, Ks is the surface loss rate constant, Kr is the retention rate constant, and Kd is the degradation rate constant. To apply the equation to a set of residue data, one provides initial estimates of Co, Ks, Kr, and Kd, and then via a non-linear curve-fitting computer program obtains the best fit values for these constants. By substituting the best fit values back into the equation, the model can then be used to accurately predict residues for bi-phasic dissipation.

For example, the dissipation of delta methrin was measured after an aerial application to soil at Taber, Alberta. The log (% residue recovered) was plotted against degree-days (this unit combines the effect of time and heat) in Figure 2. The first-order model (indicated by the dashed line) gave a poor fit to the data and predicted a $T_{1/2}$=359 degree-days. The 2CM (indicated by solid line) gave an excellent fit to the data and predicted an initial $T_{1/2}$=192 degree-days.

The $T_{1/2}$ predicted by the 2CM is much more accurate than that predicted by the ill-fitting first-order model. Accurate residue data are essential for pesticide evaluators to make the correct registration decisions. Only then can the goal of minimizing the environmental impact of pesticides be achieved.

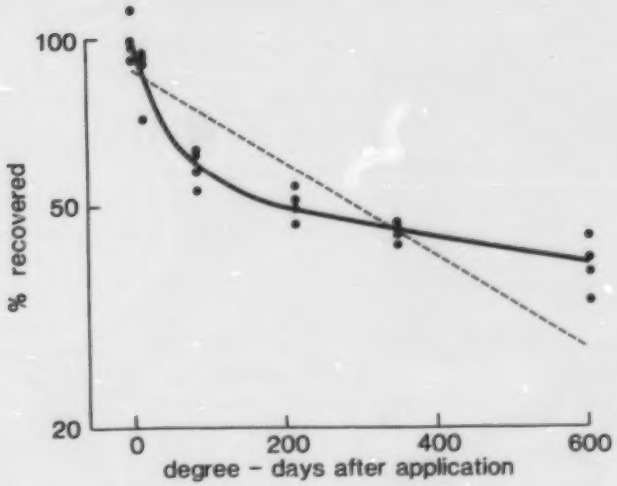

Fig. 2. Dissipation of deltamethrin on soil. Solid line is predicted by the two-compartment model; dashed line is predicted by the first-order model. Deltamethrin was aerially applied on 2 June at 10.7 g/ha; 100% recovery at week 0 was 5.1 g/ha.

A SIMPLE METHOD FOR DETECTING RESISTANCE TO BLACK POINT

R. L. Conner and J. B. Thomas

A comparison of screening techniques demonstrated that needle inoculation and vacuum infiltration provided the best means to identify lines and cultivars of soft white spring wheat with resistance to the black point pathogen Alternaria alternata. Inoculation treatments such as dips or sprays gave inconsistent results. Inoculation at anthesis allowed the best separation of resistant and susceptible lines of wheat.

Black point caused by Alternaria alternata is a major factor in the downgrading of soft white spring wheat in western Canada. Irrigation favors black point development; consequently, this disease is a perennial problem in irrigated soft white spring wheat. Resistant cultivars are generally regarded as the best means for controlling black point. Certain lines of soft white spring wheat have been found which consistently have low incidences of black point under field conditions. However, the incidence of black point in the field is not always high enough to separate resistant and susceptible entries.

Several techniques have been developed for evaluating wheat cultivars for black point resistance under controlled conditions, but the effectiveness of these inoculation techniques has never been directly compared. There has also been little agreement on the best stage of plant development at which to screen for black point resistance.

Four treatments were used to inoculate the resistant line SWS15, the moderately susceptible SWS5, and the susceptible lines SWS11 and SWS12. These treatments included dipping, spraying, and needle inoculation of the spike. Inoculations were carried out at the boot, anthesis, and mid-dough stages. In a later experiment, vacuum infiltration treatments for different periods of time, with and without the center florets of the spike removed, were also compared with needle inoculation.

Needle inoculation and vacuum infiltration both resulted in a sufficient incidence of disease to differentiate resistant and susceptible lines (Tables 1, 2). Vacuum infiltration is a rapid, reliable means of inoculation that permits the screening of large numbers of plants in a short time, whereas needle inoculation is a laborious, time-consuming technique. Spraying the heads of wheat did not readily allow differentiation of resistant and susceptible cultivars. Dipping the heads in a spore suspension resulted in an incidence of disease that was only slightly higher than the disease-free control, so it was not listed in Table 1.

Growth stage of the plant at inoculation had a significant influence on black point incidence. Disease incidence was generally lowest when plants were inoculated at the boot stage. The greater variability in disease incidence associated with inoculation at the mid-dough stage made it more difficult to differentiate lines for black point resistance. Results at anthesis were the most consistent and showed the best agreement with results from the field. This indicates that differences in black point resistance are most readily detected at anthesis and that artifical inoculation of wheat cultivars should be carried out at this stage.

The good agreement between results from natural infection in the field and artifical inoculation shows that genetic variation in kernel reaction to the fungus has a major influence on black point incidence. Differences in floral morphology may also influence black point incidence in the field. However, if resistance were only due to dissimilarities in floral morphology, then needle inoculation and vacuum infiltration should have eliminated any differences between lines.

Table 1. Incidence of black point for needle and spray inoculations with *A. alternata* at different stages of plant development.

Inoculation treatment	Breeding line	Percent black point (square root transformations) Boot stage	Anthesis	Mid-dough
Needle	SWS11	6.37a	7.79a	6.29ab
	SWS12	6.04a	7.03a	7.48a
	SWS5	4.51b	4.41bc	5.94ab
	SWS15	2.15cd	1.92de	4.78b
Spray	SWS11	1.23d	1.98de	1.00c
	SWS12	1.59cd	4.68b	1.12c
	SWS5	2.69c	3.10cd	1.55c
	SWS15	1.09d	1.00e	1.00c

a-e Within columns, values followed by the same letter do not differ (P = 0.05) according to Duncan's Multiple Range Test.

Table 2. Incidence of black point in wheat inoculated with *A. alternata* by needle and various vacuum infiltration techniques.

Inoculation treatment	Breeding line	Percent black point (square root transformation) Anthesis	Mid-dough
Needle	SWS11	6.89a	5.17ab
	SWS12	5.65ab	3.64bcde
	SWS5	3.48cde	1.60ef
	SWS15	2.36e	3.62bcde
Vacuum infiltration: 20 seconds	SWS11	4.85abcd	4.20abc
	SWS12	3.48cde	3.57bcde
	SWS5	5.00abcd	3.77bcd
	SWS15	2.46e	1.75def
Vacuum infiltration: 60 seconds	SWS11	4.94abcd	4.60ab
	SWS12	5.29abc	5.05ab
	SWS5	5.52abc	4.26abc
	SWS15	2.22e	1.42f
Vacuum infiltration: Mid-floret removed, 60 seconds	SWS11	5.64ab	5.49ab
	SWS12	4.88abcd	5.97a
	SWS5	3.10de	3.63bcde
	SWS15	3.91bcde	2.30cdef

a-f Within columns, values followed by the same letter do not differ (P = 0.05) according to Duncan's Multiple Range Test.

A ROLE FOR THE CELL WALL IN COLD HARDINESS OF WINTER WHEAT

D. W. A. Roberts

Recent work at other laboratories suggests a new interpretation of earlier studies on enzyme changes associated with cold hardening in wheat. It is suggested that cold hardiness results from an interaction of the cell wall and plasma membrane. Such an interaction would explain the difficulties that plant breeders are experiencing in transferring cold hardiness from rye and wheat grasses to wheat. Detailed studies on changes that occur during hardening in the structure of both the cell wall and plasma membrane may be required before these difficulties can be overcome.

The acreage of winter wheat on the Canadian Prairies has increased greatly in the last few years with the improvement in winter survival resulting from the advent of seeding into stubble. Growers are interested in winter wheat because of its greater yield compared with spring wheat. Early summer heat and drought tend to increase this differential in yield. However, there is still a need for cultivars with increased cold hardiness since the hardiness of the best available cultivars and parental lines is at best marginally sufficient in many areas even when wheat is sown into stubble.

A better understanding of cold hardiness and cold hardening might suggest new strategies for the development of more cold hardy cultivars. In earlier studies (Roberts 1979), we showed that changes in the proportions of two forms of the enzyme invertase in the leaves occurred during cold hardening. Many workers believe that invertase is associated with plant cells walls (for references see Roberts 1975). If so, it means that changes in wheat plant cell walls are somehow involved in cold hardening and cold hardiness.

There is a large body of evidence that suggests that the plasma membrane or outer envelope of the living contents of the cell is the site of cold injury (Levitt 1980). How then can changes in the plant cell wall be involved in changes in plant cold hardiness?

It is now possible to prepare protoplasts or plant cells that lack cell walls from both tender and hardy plants. When protoplasts and cells with walls were isolated from tender and hardy rye cultivars it was found that, although the cells from the hardy cultivar were more cold resistant than those from the tender cultivar, there was no difference between the protoplasts from the hardy and tender cultivars (Langis et al. 1985). The authors concluded that some extracellular component could be responsible for this effect. This component could easily be the cell wall.

Work on unhardened potato cells (Tao et al. 1983) showed differences in freezing tolerance between protoplasts and whole cells. The cold tolerance of the protoplasts also depended on the concentration and composition of the medium in which they were suspended. The authors suggested that these differences were caused by the presence or absence of the cell wall and degree of contact of the protoplast membrane (or plasma membrane) with the cell wall. In unhardy potatoes the effect of contact of the protoplast and cell wall appears to be a reduction in cold tolerance. The authors suggest that in potatoes the contact between the plasma membrane and the cell wall results in additional damaging strains on the plasma membrane during a freeze-thaw cycle.

Our data on wheat (Fig. 1) suggest a related possibility. The plasma membrane may be in contact with and adsorbed on the cell wall during cold stress. Cold and/or cell dehydration may injure the plasma membrane. A membrane adsorbed on the cell wall may be stabilized if the inner surface of the cell wall has the proper structure. What happens will depend on the structure of both the plasma membrane and the cell wall since both are involved in determining the strength of the adsorption forces between them (probably greater adsorption but possibly reduced

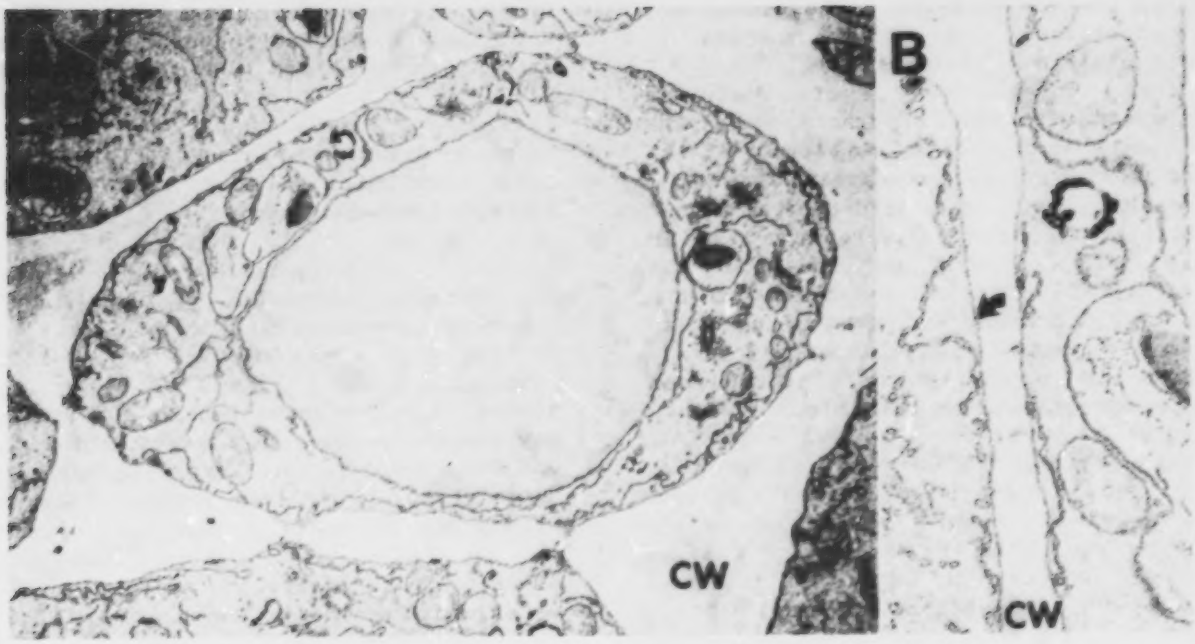

Fig. 1. A: Cell from growing point of a Kharkov 22 MC wheat plant grown under cold hardening conditions, showing cell wall (CW), plasma membrane and other living contents. B: Portion of cell wall and plasma membrane of the same cell further enlarged to show plasma membrane (arrow) lying adjacent to cell wall. (Photograph courtesy of E.B. Wagenaar, University of Lethbridge.)

adsorption forces allowing movement of the membrane relative to the wall during freezing and thawing).

One of the changes involved in cold hardening could then be changes in the cell wall and another change could be in the plasma membrane. The changes in properties of the cell wall enzyme invertase would then be explained as an indication of such cell wall changes. This does not mean that the changes in properties of the invertase have no adaptive advantage as suggested earlier (Roberts 1979) but that these changes are of minor importance. Peas, which cold harden, also show changes in the properties of root invertase associated with cold hardening (Crawford and Huxter 1977).

Work at Lethbridge on the properties of the spruce needle invertase revealed no seasonal changes in its properties even though the cold hardiness of spruce needles increases much more in winter than does the cold hardiness of wheat plants. It is possible that the mechanism involved in the hardening of these plants is different from the mechanism in plants that do not harden a great deal.

If large increases in cold resistance require large changes in plasma membrane structure during cold hardening, then large and appropriate changes in cell wall structure are also likely to be required. It is unlikely that the same genes control the details of structure of both the plasma membrane and the cell wall. Consequently, it will not likely be possible to transfer a single gene for hardiness from a related species (e.g., rye or wheat grass) to wheat and produce a large increase in cold hardiness. The need for changes in both plasma membranes and cell walls may explain the fact that octaploid triticales, which carry hardiness genes from both wheat and rye, are at best only slightly more hardy than the wheat parent even though the rye parent is much hardier than the wheat parent (Dvorak and Fowler 1978). However, some

reports suggest that extra hardiness may be transferred from wheat grasses to wheat (Limin and Fowler 1983).

In the absence of detailed information on the interaction of the cell wall and plasma membrane, it is going to be difficult to obtain the large increase in the cold hardiness of wheat cultivars needed to ensure survival in almost all winters on the Canadian Prairies. Yet the cold hardiness of the best rye cultivars and the native wheat grasses, species which are closely related to wheat, suggest that such improvement should be possible.

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FREEING POTATO PLANTS FROM BACTERIAL RING ROT

G. A. Nelson

An apical stem-cutting technique has been used successfully to free infected potato plants from the ring rot pathogen. This method can be used by potato breeders to avoid introducing bacterial ring rot along with new breeding stocks.

Outbreaks of bacterial ring rot of potatoes, caused by Corynebacterium sepedonicum, can result in serious losses to a potato crop. When seed stocks become infected with the pathogen the tubers must be discarded, the premises and equipment disinfected, and a fresh seed supply purchased. However, new seed is not always readily available, especially when a new cultivar or a breeding line becomes infected. In such situations it is necessary to select disease-free material from infected stocks. Obtaining disease-free tuber stocks by selection of visually unaffected plants in the field for several growing seasons is a lengthy and difficult process. To avoid this, quicker and more effective methods were investigated.

Ring rot bacteria are concentrated in the lower parts of potato plants. This knowledge prompted preliminary investigations at Lethbridge in which the severed tips from rapidly growing stems were used as a means for freeing plants from the ring rot pathogen. When the topmost growing points (apical stem cuttings) from Red Pontiac potato expressing mild symptoms were rooted and grown to maturity, the plants showed no ring rot symptoms. Two more generations of cuttings resulted in plants that remained free of the disease. This technique appeared to be a simple, quick and effective means for freeing potatoes from bacterial ring rot. However, no tubers were collected from mature plants originating from the final stem cuttings and there was a possibility that ring rot could have remained localized in the tubers.

To answer this question a more extensive investigation was undertaken to free infected Russet Burbank plants from bacterial ring rot by the apical stem-cutting technique and to determine if tubers from the final stem cuttings remained free of the disease for several growing seasons. Plants grown from apical cuttings taken from Russet Burbank plants with mild symptoms of ring rot developed no symptoms, nor did plants from two successive apical stem cuttings. Small tubers from mature plants of the last stem-cutting propagation, when planted in the field, produced plants that remained free of symptoms and any signs of symptomless infection. Furthermore, the disease could not be detected in successive tuber propagation over the next three years, and when extracts of tubers from the final field propagation were injected into Black Beauty eggplants, they failed to induce ring rot symptoms or infection in this extremely susceptible host.

The apical stem-cutting technique quickly and effectively freed Russet Burbank from the ring rot pathogen. Infected Red Pontiac, Norland and Warba have also been freed from ring rot by this method.

The stem-cutting technique requires a minimum of laboratory facilities and the use of careful sanitary procedures to be successful. Sensitive techniques for detecting ring rot bacteria must also be employed. The technique should be particularly useful to potato breeders to protect their valuable breeding stocks by assuring that potato lines being introduced into their breeding programs are free from ring rot bacteria before they come into contact with material already proven to be free from the disease.

MONITORING CUTWORM MOTHS IN SOUTHERN ALBERTA WITH SEX-ATTRACTANT TRAPS

J. R. Byers and D. L. Struble

The usefulness of sex-attractant traps for monitoring cutworm population levels was assessed by a large-scale field study from 1978 to 1983. The results obtained show that monitoring can detect relatively small changes in abundance of moths between years and considerably improves our ability to forecast the likelihood of infestations.

Cutworms have caused widespread and severe economic losses on many occasions since the inception of agriculture on the prairies of western Canada. The major cutworm pests are native species, which at low population levels cause little or no damage. Infestations occur whenever the culmination of a progressive increase in abundance coincides with environmental conditions that are particularly favorable for survival. A key requirement for successful management of sporadic pests such as cutworms is reliable long-term monitoring of population levels so that the increase in abundance preceding an outbreak can be detected.

Traps baited with sex-attractants are being used to monitor population levels of insect pests in many parts of the world. However, the technology is new and few detailed studies of their use for predictive monitoring have been reported. Also, the problem of relating trap catch to subsequent economic damage has been overcome for very few species. To determine if sex-attractant traps are useful for monitoring cutworm population levels under prairie conditions, an experimental monitoring system was established in southern Alberta in 1978.

The abundance of eight species of cutworm moths was monitored at 81 locations within a 13,000 km^2 (5,000 $mi.^2$) area (Fig. 1). At each site, duplicate sets of traps were placed on the east side of a north-south road allowance. Traps were spaced 10 m apart within sets and 100 m between sets. The traps used were of the cylindrical cone-orifice type with a removable end-piece (Fig. 2) and were positioned on a stake 1 m above ground level.

Each trap was baited with a synthetic sex-attractant that was specific for only one species of cutworm moth. Synthetic sex-attractants mimic natural sex-

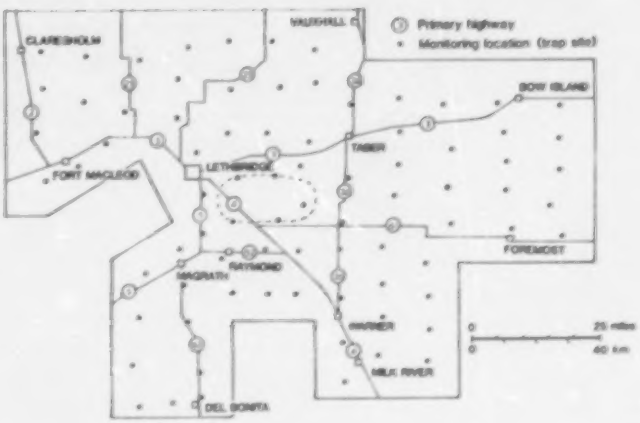


Fig. 1. Map of survey area.

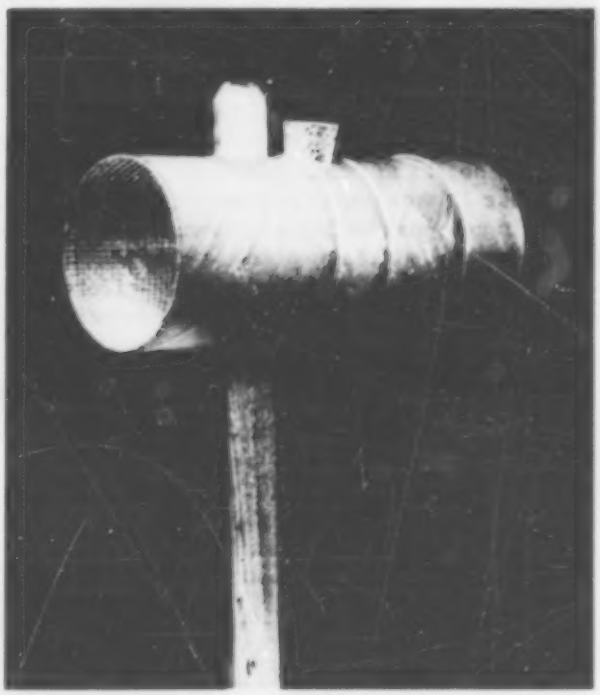


Fig. 2. Sex-attractant moth trap of the type used in this study.

pheromones which are the chemical scents produced in very small amounts by female moths to attract males of their own kind for mating. Females of each species produce a unique blend of sex-pheromone components that enable males to discriminate among females of many co-occurring species. A sex-attractant for each of the species monitored was developed at the Lethbridge Research Station by chemical analysis of the natural sex-pheromone obtained from laboratory-reared female moths. The synthetic sex-attractant blends were optimized for attractiveness and specificity through extensive field testing.

Four species were monitored during the spring and early summer: clover cutworm (spring generation), variegated cutworm (immigrant generation), bertha armyworm and Leucania commoides (no common name); and four others during mid-summer to fall: redbacked, darksided, pale western and army cutworms. The monitoring location and trap sequence were the same every year.

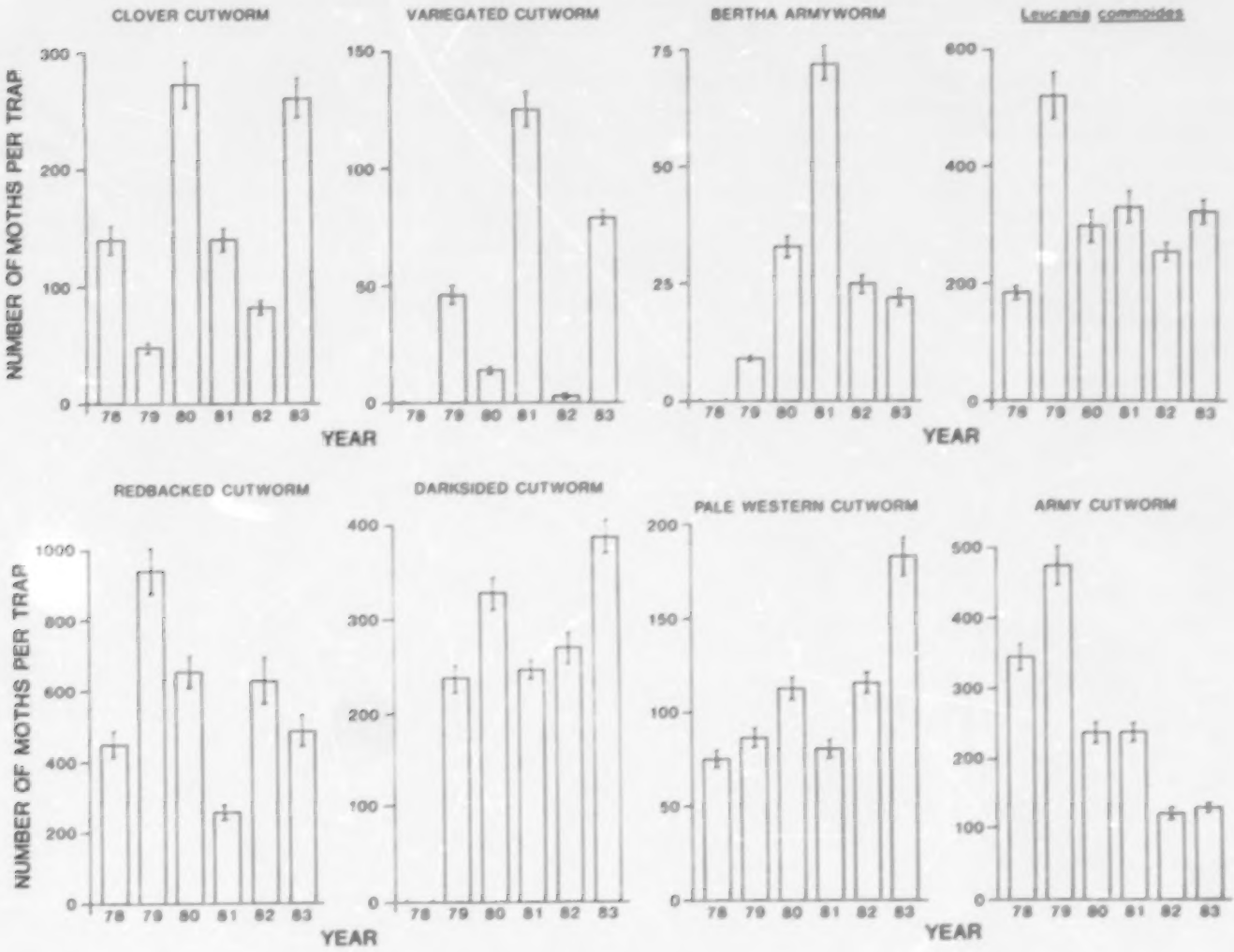


Fig. 3. Graphs showing mean number of target species moths caught in each year. Each histogram bar represents the average of 162 traps, i.e., two traps per species at each of the 81 sites. The error bars are 95% confidence intervals.

During the study 1.5 million moths were trapped, identified and counted. The mean yearly catch per trap for each species is shown in Fig. 3.

The average yearly specificity (i.e., the percent of the total moth catch that was comprised of the target species) for the respective attractants was: clover cutworm 98.3%, variegated cutworm 72.6%, bertha armyworm 59.6%; L. commoides 96.6%; redbacked cutworm 99.9%, darksided cutworm 99.5%, pale western cutworm 99.3%, and army cutworm 99.9%. The lower specificity of the attractants for variegated cutworm and bertha armyworm was partly due to the low numbers of these species caught in most years. Whenever the number of target species moths caught is low, the capture of only a few moths of other species will result in a low apparent specificity. In 1981, when the catches of both variegated cutworm and bertha armyworm were relatively high, the specificity was 82.6% and 85.8%, respectively.

Estimates of the statistical variability associated with individual traps, between the duplicate traps at each location, and among locations were obtained for each species. The within-location variance was always much less than the among-location variance, indicating that a meaningful measure of the relative population level at each location was being obtained.

Year-to-year differences in mean trap catches were frequently significant at the 95% confidence level (Fig. 3) and it is clear that the monitoring system could detect relatively small changes in population levels between years. There was good correlation between the level of moth catches and the risk of subsequent larval infestations for the two species, bertha armyworm and pale western cutworm, that caused economic damage within the survey area during the course of the study, in 1981 and 1983 respectively.

The results of the study indicate that a reliable measure of cutworm population levels can be obtained using sex-attractant traps and that the potential for outbreaks can now be predicted with considerably greater precision than has been previously possible.

WINTER STORAGE CONDITIONS CRITICAL FOR ALFALFA LEAFCUTTER BEES

K. W. Richards and G. H. Whitfield

Storage time and temperature significantly affect survival and emergence of adult leafcutter bees and their synchronization with alfalfa bloom. High survival and rapid adult emergence during incubation occur when cocoons are stored at 5°C for 7 to 10 months. For cocoons requiring storage longer than 12 months, 10°C provides good survival in a short emergence period. Cocoon storage longer than 17 months is not practical because of high mortality.

Cocoons of the alfalfa leafcutter bee, the most important alfalfa pollinator in Canada, are normally placed into cold storage at 0-10°C for 7-10 months to reduce losses by parasites and predators and to arrest prepupal development until adult bees are needed. Prepupae are removed from cold storage and placed into high-temperature incubators (30°C) for about 3 weeks in early June to synchronize adult bee emergence with the beginning of alfalfa bloom in the field.

Duration and temperature of cold storage and subsequent temperature of incubation are important factors that influence the emergence of adult leafcutter bees. The lower threshold of development for bee prepupae during incubation has been reported to be 15.7°C, the optimum is 30-32°C, and the upper threshold is 38°C. An inverse relationship has been observed between the length of time for prepupae to complete development and the length of time that prepupae are kept in cold storage.

When commercial beekeepers place the leafcutter cells into storage in the fall, they must decide which temperature and length of storage to select to provide viable bees for placement in the field at the appropriate time. Since bee cells are now exported to countries in both the northern and southern hemispheres, synchronization of length of storage, date of shipment, and length of incubation period is essential to permit bee emergence at the proper stage of crop development. Consequently, beekeepers require quantitative information on the effect of various storage periods, in combination with different temperatures, on the survival and length of the emergence period during incubation of leafcutter bees.

In a 22-month study at Lethbridge, 1000 cocoons were removed each month from each of four temperature-controlled environmental cabinets and incubated.

The emergence of leafcutter bee adults was significantly affected by both storage time and temperature. Percentage emergence increased greatly after a short period of cold storage at all temperatures examined (Fig. 1). There was 61% emergence from cocoons incubated at 30°C without cold storage and up to 98% emergence after 4 to 5 months of cold storage. At temperatures of -5 and 0.5°C, emergence decreased to less than 50% after 14 months of storage. Emergence remained greater than 80% at 10°C for up to 17 months. At all temperatures, there was less than 10% emergence after 22 months of storage. Under western Canadian conditions, the bees must be used the following season and not stored for another year.

It is important for beekeepers to synchronize incubation of bee cocoons with the commencement of alfalfa bloom, and a fairly narrow period of emergence is preferred to ensure that most bees are ready to emerge soon after cocoons are placed in the field.

For cocoons not subjected to a cold period, 135 days were required for 90% of the bees to emerge after first emergence had taken place. For all storage-temperature treatments, the emergence period decreased significantly after 4 to 6 months; however, at temperatures of -5 and 0.5°C the emergence period then increased significantly after 8 and 9 months, respectively. For storage temperatures of 5 and 10°C the emergence period remained low (less than 12 days) for up to 14 months and was significantly lower at 5°C than at 10°C during the normal storage interval of 7-10 months. At

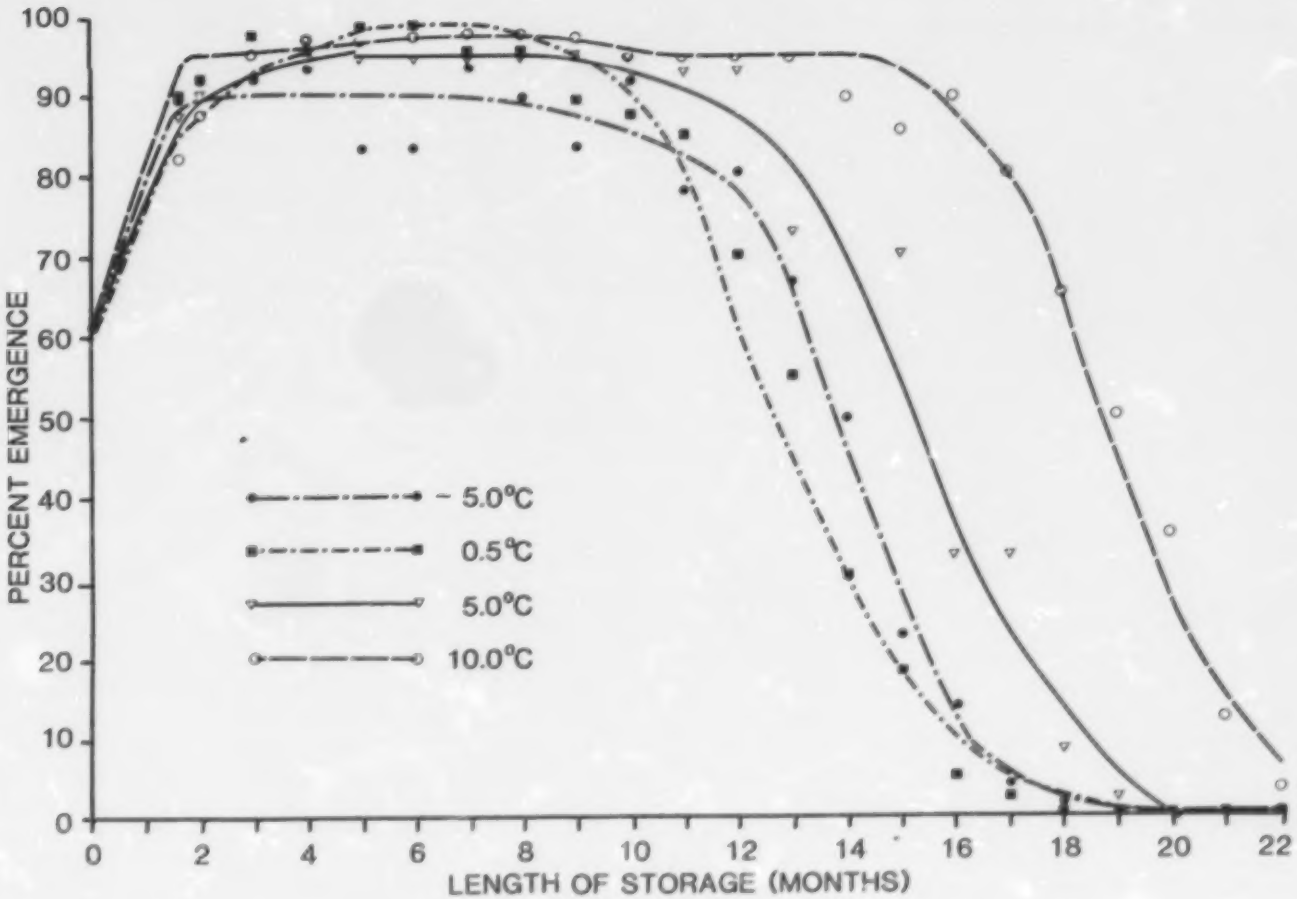


Fig. 1. Percent emergence of leafcutter bee adults at four temperatures and 0-22 months of storage.

10°C, however, the emergence period still remained low (< 20 days) for up to 20 months of storage, indicating that this storage temperature would be suitable when long-term storage of bees is expected.

For high survival and rapid completion of adult emergence during incubation of cocoons, 7-10 months of storage at 5°C is recommended. In cases where cocoons are to be held in storage for periods greater than 12 months, a higher storage temperature of 10°C will provide good survival and a short emergence period for up to 17 months of storage. A minimal storage period of 2 months is suggested, regardless of the storage temperature selected, to ensure adequate survival of prepupae during incubation. Storage of prepupae longer than 17 months is not practical because of high mortality, which can occur at all temperatures.

TIMING CONTROL OF A PARASITE OF THE ALFALFA LEAFCUTTER BEE

G. H. Whitfield and R. W. Richards

Miniature microprocessors that measure air temperature and degree-days during incubation of leafcutter bee cells can be used to predict parasite emergence. This assists beekeepers in timing control measures.

The most common insect pest associated with the commercial production and maintenance of leafcutter bees, and one which can cause serious losses in western Canada each year, is the chalcidoid parasite, Pteromalus venustus. Incidence of parasitism by this tiny wasp has been kept low (ca. 1%) by careful management techniques. However, in some instances, losses of bees have exceeded 50%, emphasizing the need for continued surveillance and control.

The parasite overwinters as a larva in alfalfa leafcutter bee cells where it develops into an adult and emerges in the spring when cells are placed into high-temperature incubation. Adults mate immediately, and the females lay eggs through the leaf pieces comprising the cocoons of healthy bee prepupae. Parasite larvae feed on the bee prepupae and often completely consume the body contents. Because up to 110 eggs can be laid by a single female wasp, the potential for high parasitism and serious losses of leafcutter bees during cell incubation is great. Precise construction of hives, controlled incubation, use of light traps, and physical separation and tumbling of bee cells are recommended practices for reducing the incidence of parasitism.

Another method of controlling parasites is the use of dichlorvos resin strips in the incubator. This method is intended to reduce the populations of emerging parasite adults and to prevent parasitism during incubation. However, periods of long exposure to dichlorvos may lead to adult bee mortality, and it is recommended that the strips only be placed in the incubator just prior to the commencement of parasite emergence and that they be removed when parasite emergence is complete. In recent studies, we have investigated a method of predicting when parasites emerge so that control activities can be more accurately timed.

In our studies, leafcutter bee cells known to be parasitized were incubated at several constant temperatures and monitored to record when adult parasites emerged. By determining how many days it took for parasites to complete development and emerge at various incubation temperatures, we were able to estimate when adult parasites would emerge in commercial incubators. To develop, insects require exposure to temperatures above a minimum value, referred to as the base temperature. As temperatures increase, the number of days required for insects to complete one stage of their life cycle and enter the next decreases.

Because temperatures can vary during the time an insect is maturing, we record development in terms of degree-days. In this way, regardless of the temperature the insect is exposed to, the effect it has on insect development can be calculated by taking the difference between exposure temperature and the base temperature times the number of days the temperature is maintained to obtain the number of lapsed degree-days. By knowing the number of degree-days necessary for an adult parasite to complete development and the number of degree-days it has been exposed in the incubator, we are able to accurately predict when the parasite will emerge from the bee cell.

In the laboratory we determined a base temperature for development of 15°C for which initial adult parasite emergence would occur at 150 degree-days and maximum emergence would occur at 165 degree-days. We compared these estimates to time of actual emergence of parasites in a commercial incubator. For a sample size of 700 parasitized leafcutter bee cocoons, we observed that adult parasite emergence took place almost exactly as we had predicted.

Several companies in Canada and the United States manufacture and market devices for measuring degree-days. These miniature microprocessors are battery-operated, self-contained and can withstand wide fluctuations in temperature and humidity. When programmed with the appropriate base temperature, they automatically monitor air temperature and determine the number of lapsed degree-days each day. Use of one of these devices coupled with the information provided here on base temperature and accumulated degree-days for parasite emergence will allow beekeepers to accurately predict adult parasite emergence during incubation of leafcutter bee cells. Control measures can then be scheduled to obtain the best control of parasites without unduly affecting the emergence of adult bees.

ALFALFA LEAFCUTTER BEE: A POTENTIAL VECTOR FOR VERTICILLIUM WILT

H. C. Huang and K. W. Richards

Studies in commercial alfalfa fields revealed that the alfalfa leafcutter bee is potentially an important agent for dissemination of the wilt pathogen Verticillium albo-atrum because it utilizes diseased leaf tissue for making brood cells, carries the pathogen on its body, and transports the pathogen to new infection courts. To minimize the danger of spreading verticillium wilt, only fields with healthy alfalfa stands should be used for seed production.

The alfalfa seed industry is rapidly expanding in the Canadian prairie provinces. The area for pedigreed alfalfa seed production in Canada increased from 2270 ha in 1976 to over 17,000 ha in 1986. Of the total production area in 1986, 93% was located on the prairies. This rapid expansion is attributable to the use of the alfalfa leafcutter bee as a pollinator. Seed producers use up to 50,000 bees to pollinate one hectare of irrigated alfalfa. Production of this domesticated bee has become an important agricultural industry in western Canada.

Verticillium wilt of alfalfa is a serious threat to alfalfa production in British Columbia and Alberta. Previous studies showed that a number of alfalfa pests and predatory insects served as agents for dispersing spores of the verticillium wilt pathogen. Since alfalfa leafcutter bees are important in alfalfa seed production, a study was carried out in 1982 and 1983 to investigate the role of this pollinating insect in dissemination, inoculation, and preservation of the verticillium wilt pathogen of alfalfa.

Leafcutter bees released to the field cut leaf pieces from alfalfa plants and transported them to the hive for constructing brood cells. The verticillium pathogen was isolated from leaf pieces in brood cells and loose leaf pieces in the hive. Over 50% of the cells yielded one or more leaf pieces with V. albo-atrum (Table 1). Incidence of the pathogen on unsterilized leaf pieces was higher than on the surface-sterilized leaf pieces. This suggests that the pathogen is also carried mainly as a surface contaminant and that only a small percentage of the leaf pieces originates from diseased leaves.

When bees were examined after foraging in the diseased alfalfa field for 6-8 weeks, 30% of them were contaminated with spores of V. albo-atrum. These spores were trapped along with pollen grains in different parts of the body including the mouth, legs, the propodium, and membranes between the abdominal segments. Some of the spores germinated and infected the alfalfa pollen grains carried by the bees.

These findings indicate that the alfalfa leafcutter bee is a potential agent for spreading verticillium wilt of alfalfa because of its ability to cut infected leaf pieces for making bee cells, to trap spores of the pathogen on its body, and to collect alfalfa pollen grains, which provide an infection court for the pathogen. Contamination of the pathogen on leaf pieces of the brood cell is of particular significance in long-distance dispersal of the pathogen because leafcutter bee cells are shipped between alfalfa production areas and between countries. Contamination of bee bodies by spores of V. albo-atrum may result in infection and destruction of the bee-transported pollen grains by the pathogen. If a high percentage of the bee population in a field is contaminated by the pathogen, it may reduce the pollination efficiency of these bees and thereby decrease alfalfa seed yield.

In addition to alfalfa pests such as pea aphid, alfalfa weevil, and grasshopper, pollinating insects such as leafcutter bees may also be important transporters of the verticillium wilt pathogen to brood cells and infection courts such as pollen grains and flower parts. In order to minimize the danger of spreading this important disease, alfalfa producers should avoid using fields infested with V. albo-atrum for seed production.

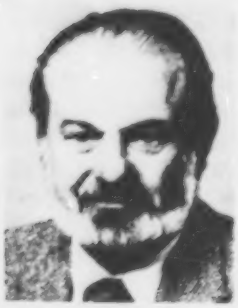
Table 1. Contamination of leafcutter bee cells and loose leaf pieces of alfalfa by the pathogen V. albo-atrum.

Hive[1]	Treatment	Brood cells % infested	Brood cells % infested leaf pieces	Loose leaf pieces % infested
1	Surface-sterilized[2]	50	8	8
	Unsterilized	100	47	38
2	Surface-sterilized[2]	53	4	1
	Unsterilized	69	16	14

[1]Two thousand leafcutter bees in each hive were released to the diseased alfalfa field for 8 weeks.

[2]Leaf pieces were surface-sterilized in 70% alcohol for 90 seconds.

MORTALITY OF ALFALFA INSECTS AFFECTED BY AN ENTOMOPHAGOUS FUNGUS



A. M. Harper and H. C. Huang

An entomophagous fungus, Verticillium lecanii, was able to attack and reduce populations of several species of aphids, one species of grasshopper, and one predatory bug under laboratory conditions. It may be a potential biological control agent for some insect pests on greenhouse crops and perhaps on irrigated field crops.

The fungus V. lecanii is reported to attack many species of insects. In this study a strain of the fungus was isolated from soil taken from Mount Allen near Banff, Alberta. The insects were sprayed with an aqueous suspension of spores or were dipped in aqueous suspensions of the fungus. In another experiment, grasshoppers were fed on alfalfa plants sprayed with spore suspensions of V. lecanii. At the end of each experiment isolations were made from dead and live insects to determine whether individual insects were infected or killed by this fungus. The insects used in the experiments are listed in Tables 1 and 2.

Spraying aphids with fungal spores significantly reduced populations of pea aphid and rose grass aphid. Populations of green peach aphid, spotted alfalfa aphid, and oat birdcherry aphid were also lower than those of the controls, but not always significantly.

The disease developed slowly, as dead aphids were not present until about 5 days after treatment. The number of aphids generally increased during the course of the experiments in both the treatments and the controls because the insects inoculated with the fungus were able to produce offspring before they were infected and killed.

Compared with the untreated controls, the population reduction of grasshoppers feeding on alfalfa plants sprayed with a spore suspension of the fungus was 22% and varied from 8 to 37% in the three tests. The fungus was recovered from 72-93% of the dead insects and from 56-95% of the insects that were still alive at the end of the experiment.

In the experiment in which grasshoppers were dipped in the spore suspension, mortality was 100% and the fungus was recovered from 95% of the treated grasshoppers. Mortality of western damsel bugs was also high in similar experiments, but ladybird beetle and European corn borer larvae were not significantly affected (Table 2).

The cause of death of the insects by this fungus may be due to toxins. Japanese workers have isolated a new insecticidal compound, bassianolide, from the fungal mycellium. British workers found that secondary metabolic products from the fungus were insecticidal.

Other workers have shown that the pathogenicity of the fungus is affected by temperature and humidity and that it is most effective for controlling insect pests when humidity is very high. Because the humidity in southern Alberta is low, the fungus may be of limited value for control of insect pests on dryland crops. However, it might be useful in irrigated areas where moisture can be controlled.

The fungus appears to have the potential for use in integrated pest management programs. Although it controls aphids, the fungus would have to be used with caution as it readily kills the western damsel bug, an important aphid predator. Further research is necessary to determine whether this pathogen has a place in the control of plant pests in agricultural areas.

Table 1. Average numbers of live aphids 10-14 days after spraying with spores of the fungus *V. lecanii*.

Species		Avg no. of aphids on plants
Pea aphid	Check	1301
	Treatment	341
	% reduction	74
Rose grass aphid	Check	952
	Treatment	390
	% reduction	59
Green peach aphid	Check	332
	Treatment	100
	% reduction	70
Oat birdcherry aphid	Check	2034
	Treatment	1634
	% reduction	20
Spotted alfalfa aphid	Check	1872
	Treatment	872
	% reduction	53

Table 2. Infection of migratory grasshopper, western damsel bug, ladybird beetle, and European corn borer dipped in a spore suspension of the fungus *V. lecanii*.

	Corrected % mortality	% of insects with *V. lecanii*			
		Treated		Control	
		Dead	Alive	Dead	Alive
Migratory grasshopper	100	99	0	0	0
Western damsel bug	82	100	82	17	13
Ladybird beetle	13	0	0	0	0
European corn borer	0	0	0	0	0

MANY SPECIES OF APHIDS IN ALBERTA

A. M. Harper

One hundred and forty seven species of aphids have been found in Alberta, along with 12 species of tiny wasps that parasitize the aphids, and two species of wasps that kill the parasitic wasps. Nearly all crops and trees are attacked by aphids. Although many species of aphids occur in Alberta only a few are serious pests.

Damage

Aphids are among the world's most destructive insect pests. They vary in color and may be red, pink, yellow, brown, green, purple, or black. They reduce the vigor and yield of plants, contaminate edible parts, transmit destructive plant diseases, and kill plants if the infestation is great.

Most species have a narrow host range but some, like the green peach aphid and the black bean aphid, attack many different plants. The green peach aphid may need to be controlled in greenhouses and on potatoes. The pea aphid, Acyrthosiphon pisum, damages pea and alfalfa plants and may also carry spores of the alfalfa verticillium wilt pathogen. Five species of grain aphids infest grasses, cereals, and cover crops in Alberta. They may also transmit the virus that causes barley yellow dwarf, a disease that seriously affects cereal crops.

One of the most severe aphid infestations of grain on record occurred in 1986 in Alberta when the greenbug, Schizaphis graminum, infested about 1 million ha of grain. Over 100,000 ha were sprayed with dimethoate by air or with malathion by ground sprayers. Some of the late-seeded crops were so badly damaged that they were not worth spraying and were just ploughed down. The crop loss on many farms amounted to over 50%. This aphid caused much damage even when numbers were relatively low because it injected a toxin into the plant and damaged the plant by removing nutrients. The damage was accentuated by the severe drought in July.

Another severe aphid infestation occurred in 1956 when the corn leaf aphid, Rhopalosiphon maidis, infested nearly every acre of late-planted barley and destroyed over 110,000 ha of the crop.

The sugarbeet root aphid, Pemphigus betae, has caused serious problems to sugarbeets in Alberta, and in the late forties and early fifties was the limiting factor for sugarbeet production. During that period some fields yielded less than 12.5 tonnes/ha, which was well below production costs.

Biology and Reproduction

Aphids are prolific. They have the unusual ability to produce living young without mating so their population can increase rapidly under favorable conditions of temperature and moisture. In warm climates they produce live young all year. In colder climates they generally produce sexual forms in fall. The males and females mate and the females produce one or more eggs. The young that hatch from the eggs in spring produce living female young that, without mating, can soon produce new winged or wingless female offspring. These, in turn, produce other female young. This type of reproduction is repeated throughout the season and populations can become very large.

Control

Natural controls such as parasites, predators, and unfavorable weather conditions play an important role in restricting aphid populations. Sometimes natural controls prove inadequate and fail to keep aphids below economic levels as was the case with the green bug this year, and insecticides must be applied to control the pests. Aphids may also be controlled by growing resistant varieties, modifying irrigation and cultural practices, and introducing parasites, predators, and aphid diseases. Often two or more of these methods are used in combination.

The pea aphid appears to be under satisfactory natural control in forage alfalfa. In alfalfa there are at least 30 insects that help to keep the aphid under control, including ladybird beetles, syrphid fly larvae, lace wing adults and larvae, anthocorid bugs, and small parasitic wasps. One parasitic wasp, Aphidius smithi, was reared in large numbers and released throughout Alberta and has become very important in controlling this aphid.

If pea aphid populations are high and the crop is past the 10% bloom stage, the crop can be cut to control the aphids instead of spraying. Cutting will also aid in controlling some of the other pests of alfalfa. The use of insecticides for pea aphid control is seldom necessary. If present controls do not work in the future, pea aphid-resistant cultivars available in other parts of the world could be used as a basis for the development of resistant cultivars for Alberta.

The sugarbeet root aphid was once a problem on sugarbeets in Alberta. The aphid has two hosts: it lives part of its life cycle on poplar trees and part on the roots of sugarbeets or some other summmer host. The aphid is controlled on poplar trees by anthocorid bugs, leucopid fly larvae, ladybird beetles, and sometimes syrphid fly larvae. On sugarbeets the aphid is controlled by syrphid fly larvae, cloropid fly larvae, and a fungus disease, Entomophthora aphidis. Larvae of the chloropid fly have been found wherever a sugarbeet aphid infestation has been found and they are the main factor keeping the aphid under control. If soil insecticides are applied, the root aphids are controlled and the predators are killed. Aphid populations in insecticide-treated areas are often as great as or greater than those in untreated areas at the end of the season. Sugarbeet root aphid-resistant cultivars have been found that could be grown in Alberta but have not been selected for other desirable characters. At present, damage to sugarbeets in Alberta by the root aphids is being kept to a low level by early and frequent irrigation, planting the crop as early as possible, keeping soil fertility high, refraining from the use of insecticides, and allowing biological agents to continue to control the pests. The controls, without insecticides, have worked satisfactorily for over 30 years.

Little Chance of Eradicating Aphids

Aphids have been present in Alberta since ancient times. A few years ago an aphid was found embedded in clear amber in the tailings of an open-pit coal mine near Medicine Hat, Alberta. The bentonite that overlaid the amber-bearing coal was determined radiometrically to be about 72 million years old. Fossils of five other species of aphids have been found in amber on the shores of Cedar Lake, Manitoba. Other fossil aphids have been found in England and Denmark. Those from Denmark were in amber calculated to be 35-50 million years old. Aphids have a remarkable ability to readily adjust to adverse and changing conditions and they present scientists with many unusual and interesting challenges.

CONTROL OF GRASSHOPPERS WITH TWO FORMULATIONS OF THE PYRETHROID INSECTICIDE DELTAMETHRIN

D. L. Johnson and B. D. Hill

Deltamethrin is a synthetic pyrethroid insecticide recently registered for grasshopper control. Control can be achieved with much smaller quantities of this compound than would be required with other insecticides. Results of a study combining field efficacy experiments, laboratory toxicological evaluations, and residue analyses indicated good agreement between laboratory and field tests. Our tests of a new flowable formulation indicated that grasshoppers can be controlled with even less active ingredient.

Grasshoppers are serious pests of grassland and crops in the Canadian Prairie provinces. Economic injury is effected through removal of foliage, resulting in a reduction in forage available to livestock and in reduced crop yield. Efforts to minimize losses focus on the use of insecticides to destroy grasshoppers in fields, pastures and roadsides. Of the 1.5 million ha infested in Alberta in 1984, >300,000 ha were sprayed to control grasshoppers. In 1985 and 1986, approximately 700,000 and 600,000 ha in Alberta were sprayed. The long-lived chlorinated hydrocarbon insecticides are no longer registered for use, and until recently the recommended insecticides were organophosphates and carbamates applied at rates of up to 1125 g active ingredient (AI)/ha.

The synthetic pyrethroids are a relatively new group of insecticides known for their high toxicity to insects and their fast action. Generally, smaller quantities are required for control. Deltamethrin at rates of 5.0 to 7.5 g AI/ha was registered in Canada in 1982 for ground application to control grasshoppers. To provide data for the registration of aerial spraying, we conducted experiments to determine the efficacy of aerial applications of deltamethrin. Initial experiments were conducted on two pastures near Claresholm, Alberta, with Decis 5.0 EC, an emulsifiable concentrate of deltamethrin with 5.0% AI.

Efficacy tests of insecticides tend to be done in one of three ways. Standard toxicological studies are conducted in the laboratory and generally yield probit equations. These equations predict the proportion of insects expected to die given a certain rate of insecticide application. Field studies tend to be more pragmatic, combining carefully monitored application methodology with ecological sampling of the pest populations so that the actual effects of the insecticide on the abundance and distribution of the insect can be determined. A third area of research involves the determination of the precise amount of the insecticide applied, and of the amounts of insecticide residue that remain over time as the compound degrades. With the cooperation of Dr. C. F. Hinks, Agriculture Canada, Saskatoon, we combined all three methods, so that the results of the laboratory probits could be compared with actual field results. We used the measured amount sprayed, determined from insecticide residue analysis, in the probit equations to obtain predicted grasshopper mortality. Precise estimates of the abundance of all species and age classes of grasshoppers in the pastures before and after spraying were compared with the predicted values.

We found good agreement between the analytical (laboratory sampling) and the ecological (field sampling) methods. We also found poorer grasshopper control than had been anticipated with deltamethrin. Analysis of grasshopper abundance, migration, and age structure indicated that although there were almost no living grasshoppers found after spraying, enough survivors recovered so that grasshopper populations were only reduced by 64 to 67% after 4 days (the actual numbers of grasshoppers sampled are shown in Fig. 1). Analysis of the data with and without the club-horned grasshopper, a species suspected of being less susceptible because of its early

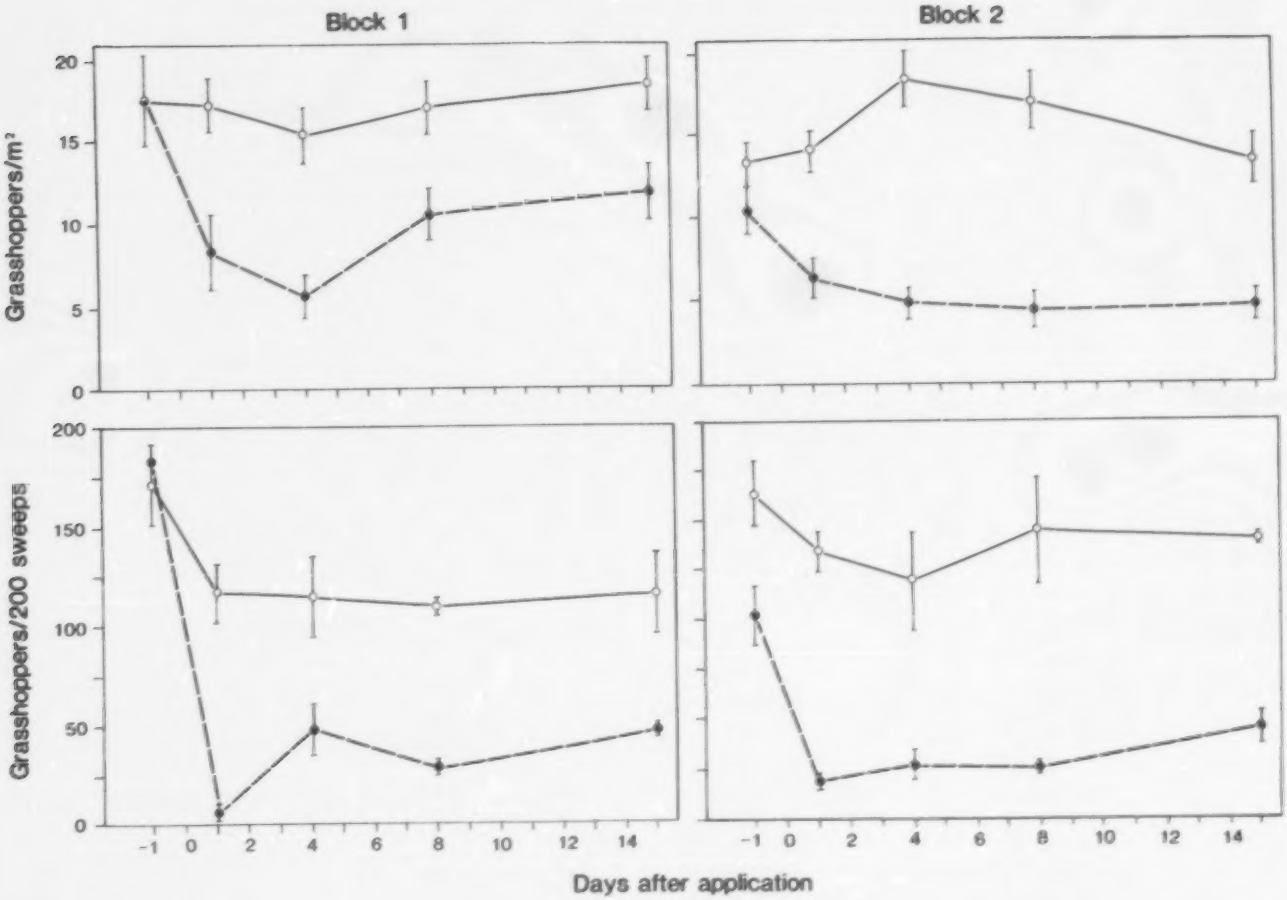


Fig. 1. Numbers of grasshoppers before and after application of Decis EC on day 0. Means (±SE) are shown for the treated (0) and untreated (0) plots. Estimates of the number of grasshoppers per m^2 were based on sampling with bottomless cages dropped onto the grass.

maturity, resulted in only a 4% higher estimate of mortality. Residue analysis indicated that the vegetation and litter in two pastures received 79 and 68% of the deltamethrin applied at 7.2 g/ha. Using these figures, the predicted estimates of mortality from the probit equations developed by Dr. Hinks in independent laboratory experiments were 73 and 68%, very close to the field results. Subsequent field experiments have indicated a maximum of 80-85% mortality achieved. Apparently, field tests by earlier researchers, which indicated reductions in grasshoppers numbers of >95%, were based on sweep-net sampling only, and this technique cannot distinguish between death and temporary paralysis of grasshoppers.

The variables affecting the efficacy of an insecticide can be roughly divided into three areas: characteristics of the insect, environmental factors (such as wind, temperature, sunlight and application parameters) and attributes of the formulation. These three groups of factors act and interact to produce the success or failure of a new compound in controlling insects. We tested an experimental flowable formulation of deltamethrin produced by the manufacturer, which consists of finely ground deltamethrin suspended in water with a combination of chemical agents that improve dispersion and suspension of the insecticide. Unlike the EC, in which the deltamethrin is dissolved in xylene, the flowable formulation does not contain dissolved deltamethrin.

Most of the deltamethrin is adsorbed onto the minute particles of chemical agents, and theoretically the deltamethrin is readily transferred to the grasshopper from these particles. In field tests, we found the new flowable formulation to be definitely superior to the EC (Table 1). Subsequent field experiments with a range of rates indicated good grasshopper control can be achieved with as little as 2 g AI/ha. This increases the safety advantage of using this recent addition to the arsenal available for use against grasshoppers. Although, gram for gram, deltamethrin is more toxic to mammals than most of the other four grasshopper insecticides in common use (the danger of acute oral toxicity to rats is 0.1, 8.1, 2.4 and 5.7 times higher than carbofuran, carbaryl, chlorpyrifos and dimethoate, respectively), less insecticide is required for grasshopper control (28, 110, 56 and 42 times more is required per unit area for the other chemicals listed, respectively).

We have conducted a series of experiments to determine why the flowable formulation performs so much better. Apparently it is not only more available to the insects as the particles are picked up from vegetation, but it is also more toxic when ingested along with food, and when it contacts grasshoppers directly. It also tends to degrade more slowly under outdoor conditions, so that it is capable of providing much more than the 1-3 days of activity normally attributed to the EC formulation. The improvement in efficacy of the flowable formulation seems to apply only to grasshoppers, and not to other insect pests. Experiments designed to discover the reasons for these differences will provide improvements in the management options available to growers in the short run. In the long run, these studies will support our goal of improving the efficiency of insect control, so that better crop protection with less insecticide can be achieved.

Table 1. Percentage mortality attributable to the Decis formulations, when applied to rangeland at a rate of 7.5 g AI/ha.

	Days after treatment		
Formulation	1	4	8
Decis EC	83	81	77
Decis FLOW	96	98	99

SCREENING FOR SNOW MOLD RESISTANCE IN WINTER WHEAT

D. A. Gaudet

Snow molds cause extensive damage to overwintering cereals, grasses, and legumes in central and northern Canadian prairies and currently prevent production of winter wheat in these regions. An isolate of Coprinus psychromorbidus, determined to be the most pathogenic over a wide range of low temperatures is currently being used in a breeding program to screen winter wheat for resistance to snow mold.

Two forms of cottony snow mold, incited by Coprinus psychromorbidus, have been identified: a sclerotial (SLTB) and a non-sclerotial (LTB) form. Surveys have shown the LTB form to be the most frequently collected in Alberta, Yukon, and Alaska.

The only practical control for snow molds is through the use of resistant crop varieties. This study was undertaken* to determine variation in pathogenicity and to establish the temperature range for development of cottony snow mold by LTB isolates on winter wheat. This research will be used in a program to develop an effective screening method for resistance to the disease.

The LTB isolates used in this study were sampled from winter wheat, fall rye, grasses, and perennial forages from south, central, and northern Alberta. Some isolates have been maintained on artificial media for as long as 38 years. Inoculum for each isolate was produced on a sterile oat-rye medium.

Winter wheat (Triticum aestivum 'Winalta') was grown at 20°C for 3 weeks, hardened at 2°C for 3 weeks, and inoculated. Pots containing inoculated plants were placed in refrigerated storage rooms set at different temperatures. Duration of the incubation period for the different isolates and temperatures was selected to obtain differential responses in percentage survival among treatments. Following incubation, the plants were transferred to a greenhouse set at 20°C for 3 weeks to determine the percentage survival.

In the first study, plants were inoculated with the LTB isolates W1, W2, W5, W10, W14, W17, LTB-160, and incubated at -7, -5, -3, -1.5, 0.5, and 2°C. Isolates W1, W10, and LTB-160 were incubated with the wheat plants for 13 weeks and the others were incubated for 15 weeks.

Figure 1 illustrates the percentage survival of winter wheat plants inoculated with three isolates at -7, -5, -3, -1.5, 0.5, and 2°C. Percent survival in the uninoculated controls after 13-15 weeks of incubation was 100% for all incubation temperatures.

The LTB isolates were placed into three groups according to their ability to kill plants at the different incubation temperatures. These groups corresponded to Types A, B, and C, identified by Ward et al. (1961) on the basis of cultural behavior, hydrogen cyanide production, and pathogenicity on orchardgrass and alfalfa. Type A was represented by W1 and also contained the isolates W10 and LTB-160. W1 caused the largest reduction in percentage survival after 13 weeks of incubation and reduced winter wheat survival to 0% at -3 to -7°C after 13 weeks (Fig. 1). At 0.5 and 2°C, survival of wheat inoculated with the W1 isolate was 90% at 0.5°C and 100% at 2°C.

Type B was represented by W2. Survival of inoculated winter wheat after 15 weeks at -7°C was 96% and decreased to 4% at 0.5 and 10% at 2°C (Fig. 1). Type C is represented by W17 (Fig. 1). This isolate caused only slight mortality over the range of incubation temperatures.

In a second study, winter wheat was inoculated with the W1 isolate and the isolates recently collected from central and northern Alberta (LTB-161, -162, -164, -176, and -178) and incubated at 0.5, -3, -5, -8 or -10°C. Plants were incubated at -3 or -5°C for 10 weeks and at 0.5, -8, or -10°C for 13 weeks. Variation among isolates for percent

*Partially funded by a Farming for the Future grant.

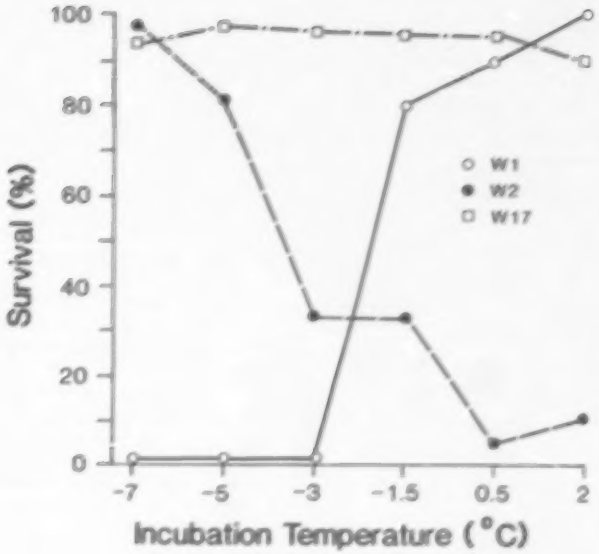


Fig. 1. Percentage survival of winter wheat plants inoculated with LTB isolates of C. psychromorbidus, and incubated for 13 or 15 weeks at -7, -5, -3, -1.5, 0.5, and 2°C, and for 3 weeks at 20°C. Survival was 100% in uninoculated controls.

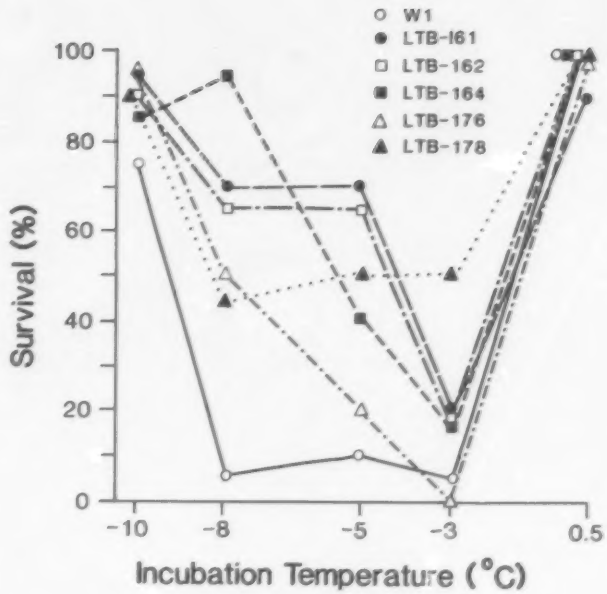


Fig. 2. Percentage survival of winter wheat inoculated with LTB isolates, and incubated at -10, -8, -5, -3, or 0.5°C for 10 or 13 weeks, and at 20°C for 3 weeks. Survival was 100% in uninoculated controls.

survival at the different incubation temperatures was tested using analysis of variance.

The optimum temperatures for development for the LTB isolates were -3°C followed by -5 and -8°C. W1 was the most aggressive isolate, as in the first study; percentage survival was reduced to the greatest extent at the temperatures of -3 and -5°C after 10 weeks of incubation and at -8°C after 13 weeks of incubation (Fig. 2). All isolates except LTB-176 and 178 grew from the oat-rye inoculum and colonized the leaves to a small extent at -10°C. At 0.5°C, the isolates slowly colonized wheat leaves.

LTB isolates varied in their ability to damage winter wheat under controlled conditions. This variability in pathogenicity was due, in part, to different temperature optima for pathogenicity among the different isolates.

The LTB isolates 161, 162, 164, 176, and 178, which were recently collected from diseased winter cereals in northern Alberta, were similar to Type A isolates based on their optimum temperature for pathogenicity. However, the isolates varied in pathogenicity at -8, -5, and -3°C (Fig. 2). Interestingly, the most aggressive LTB isolate tested (W1) and the moderately aggressive isolates W2 and W10 have been maintained through repeated transfers on artificial media since 1948-1950 without apparent loss in pathogenicity. This suggests that pathogenicity is a stable characteristic among certain LTB isolates.

Type B isolates were less pathogenic than Type A isolates. Type C isolates colonized winter wheat leaves between -3 and 0.5°C but were only weakly pathogenic. Type B and C isolates exhibited similar optimum temperatures for disease development on winter wheat leaves. Of the LTB isolates tested, the Type A isolate, W1, appears to be the most suitable for use in a screening test to select winter wheat varieties or lines resistant to cottony snow mold because it is highly pathogenic over a wide range of low temperatures. This isolate has also demonstrated a remarkable degree of stability in pathogenicity despite storage over long periods.

Ward, E.W.B., Lebeau, J.B., and Cormack, M.W. 1961. Grouping of isolates of a low-temperature basidiomycete on the basis of cultural behavior and pathogenicity. Can. J. Bot. 39:297-306.

soil & irrigation management

POTASSIUM FERTILIZER REQUIREMENTS OF SOUTHERN ALBERTA SOILS

D. C. MacKay and J. M. Carefoot

Application of K fertilizer did not result in increased yields of potatoes or alfalfa, crops that have high K requirements. Without K fertilizer, K was released from non-exchangeable forms in the soil to meet the needs of crops, but high rates of fertilizer K resulted in conservation of K in a "fixed" form, which should be available for later crop use.

In many experiments conducted during the last three or four decades our scientists have found no benefits from application of K fertilizers to a wide variety of crops. These results were obtained on both irrigated and dryland soils. Realizing that large quantities of K must be obtained from soils to provide the high K concentrations found in most agricultural crops, we recently undertook experiments to determine the likelihood of K deficiencies in the future.

The results of research in Montana and other areas have indicated that K deficiency is more likely in dry years. In our experiments with potatoes in a rainshelter where soil moisture content could be controlled precisely, moisture stress in either the cultivated layer or the subsoil did not cause K deficiency (Table 1). While moisture stress itself reduced tuber yields, application of K gave no significant yield increases with any of the soil moisture treatments.

A 2-year rainshelter experiment with alfalfa also gave no indication of response to K fertilizers during six harvests (Table 2). The soil used in this experiment, a Cavendish sandy loam, had never received K fertilizers and because of its coarse texture would normally be considered relatively poor in available K. Examination of the changes in the readily available soil K content and of the balance sheet of K additions and removal helps to explain the reasons for these results.

Soil K that is readily available to crops is determined in the laboratory by a procedure called "exchangeable" K. In our alfalfa experiment, exchangeable K was reduced by about 20% without K fertilizer (Table 3, col. C vs. B). However, this reduction accounted for only about 70% of the K removed from the soil during cropping (col. D).

Table 1. Yield of potato tubers as influenced by soil moisture and K treatments.

	Yield of tubers (kg per container)
Rate of K (kg/ha)	
0	2.17
150	2.19
300	2.22
450	2.22
Moisture stress	
None	2.28
Cultivated layer only	2.21
Subsoil only	2.10

Table 2. Yields of alfalfa from successive harvests and K treatments.

Applied K (kg/ha)	Harvest No. 1	2	3	4	5	6[1]
0	34	118	75	80	68	257
150	35	120	76	79	64	256
300	29	115	73	77	60	251
450	28	105	69	74	61	248

[1]Includes roots and stubble.

Table 3. Fate of soil and fertilizer K during intensive cropping to alfalfa in a rainsbelter.

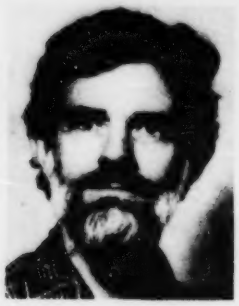
A	B	C	D	E	F	G
Fert. K applied	Exch. K in soil Initial	Final	K removed in crops	Input (A+B)	Output (C+D)	Difference (E-F)
----------g of K per container----------						
0	35.8	28.4	10.6	35.8	39.0	-3.2
7.7	35.8	31.1	11.6	43.5	42.7	0.8
15.4	35.8	35.5	11.8	51.2	47.3	3.9
23.1	35.8	39.3	11.6	58.9	50.9	8.0

On the other hand, application of K fertilizer at very high rates (23.1 g = 450 kg/ha) increased exchangeable K but not nearly enough to account for all the added K. Since K removal by the crop was not much greater than without K fertilization, some 25% of the applied K (8.0 g, col. G) disappeared as "fixed" K within the soil minerals. (The containers used in the experiment were watertight to prevent loss by leaching.)

Most soils of the Canadian Prairies are capable of releasing for crop use large quantities of K that are not detected in regular laboratory procedures used for measuring available K. This K originates from mineral compounds that are present in greater quantities in our soils than in the more highly weathered (unglaciated) soils of Montana and other areas. By a reversible mechanism in the soil, K applied as fertilizer becomes readily "fixed" in unavailable mineral forms, which prevents leaching and luxury uptake by crops, yet is available for use when required later.

These results suggest that K fertilization of crops grown on Brown and Dark Brown Chernozemic soils of this region is presently an unnecessary expense to producers, even with very intensive cropping such as that on irrigated soils. However, the application of K fertilizers would delay crop deficiencies that are certain to occur without fertilization some time in the future. A practical solution for producers might be to apply moderate amounts of K fertilizers as a conservation practice when economic conditions are favorable. In times of financial stress, the soil reserves could then be utilized to save expenses without reducing crop yields.

EFFECT OF EXCESS FEEDLOT MANURE ON CHEMICAL CONSTITUENTS OF SOIL UNDER NON-IRRIGATED AND IRRIGATED MANAGEMENT



J. F. Dormaar and T. G. Sommerfeldt

Disposal of feedlot manure is of real concern in southern Alberta. Yield data indicated that, although decomposition of feedlot manure did not keep pace with quantities applied, detrimental effects were not measurable after 10 years. Applying excess manure to soil is probably still the least expensive means of disposal.

The maximum recommended rates of manure application to non-irrigated and irrigated Dark Brown Chernozemic soils of Alberta are 27 and 67 t/ha annually (wet weights). However, information on the consequences of applying manure in excess of these recommended rates is lacking. To rectify this situation, a long-term field experiment was initiated in 1973 to determine the capacity of a Dark Brown Chernozemic Lethbridge loam for loading with feedlot manure. The objective of the part of the study reported here was to determine changes in soil organic matter characteristics of the Ap horizons of non-irrigated and irrigated soils brought about by 10 years of applying feedlot manure in excess of the recommended rate.

Cattle feedlot manure was applied annually in the autumn to two adjacent blocks of land. Application rates were 0, 30, 60, and 90 t/ha (wet weight) on a non-irrigated block and 0, 60, 120, and 180 t/ha (wet weight) on an irrigated block. The manure was incorporated by cultivating and discing. The 30 and 60 t/ha rates approximated the recommended maximum application rates for non-irrigated and irrigated land, respectively. Barley (Hordeum vulgare L. 'Galt') was seeded in the blocks each year.

Dehydrogenase and phosphatase activities in the manured plots increased with increasing rates of manure application. However, the phosphatase activity never rose above that of the soil from a native range nearby. The C and N contents increased with increasing rates of manure as well. The C:N ratios remained fairly constant, indicating that the overall N balance was being maintained even though the distribution of N varied.

Total P in the soil and in the manure added is a given quantity not subject to the various additions and losses that befall N. The data indicated that increased yields and, possibly, luxury feeding by the plant have taken P out of the soil; P increased non-linearly with increasing rates of manure. The labile inorganic P content extracted from the cultivated soil increased with increasing rates of manure, compared with soil from the native range. Similarly, feedlot manure added labile organic P to the soil.

Excess feedlot manure thus led to a buildup of many soil constituents and yet, tripling the rate of manure applied did not triple the levels of any of the soil parameters measured. Much of the manure applied at triple the recommended rates had not decomposed and was still visible.

Naturally, increased manure additions decreased the bulk density of the soil. These decreased bulk densities likely have an effect on water conservation, although bulk densities of 0.64 to 0.77 t/m^3 may be, conversely, lower than optimum for these soils in terms of seedbed quality.

Total amounts of C (in t/ha) present in the Ap horizons can be calculated by using these bulk densities and C content. Further, the amount of C applied can be calculated from the moisture and C contents of the feedlot manure applied each year over 10 years. Under both moisture regimes the proportion of C retained after 10 years decreased as excessive manure application increased.

The irrigated plots receiving 60 t/ha per year of manure gained as much C in 10 years as the non-irrigated plot receiving 90 t/ha. This is consistent with higher production and return of residues on the irrigated treatment, and indicates a more efficient humification

of added residues in the more moist environment. A more efficient humification process is indicated as well by the greater proportion of water-stable aggregates in the irrigated soils receiving manure than in the comparable non-irrigated soils. This holds even at the 180-t/ha rate.

The recommended manure rate for non-irrigated soils in this area is 30 t/ha per year. This rate maintained total organic C compared with the native range (2.67 vs. 2.63%) even though it was probably of a different quality, as evidenced by the water-stable aggregate levels. The chemical composition of soil aggregates changed under different management regimes. Triple the recommended rate under irrigation (180 t/ha) led to 8% organic C. Total C and the compounds making up this total C are not synonymous for different soils.

The effect of P amendments on soil acid phosphatase activity illustrates the dynamic nature of soil acid phosphatase. Although the manure added substrate, which stimulated phosphatase production, it also added P. This reduced the demand for soil-derived P, thereby repressing the production of new phosphatase. Even though phosphatase activity rose with manure applications, it never rose above that of the soil from the native range. This is a good example of differences in "soil quality" in spite of increased organic matter levels.

The principal objective of this study was to determine the effects on soil physical and chemical properties when disposing of feedlot manure at excessive rates of application. For many of the soil properties examined, the effects of both irrigation and feedlot manure additions were clearly apparent. Those properties measured usually increased. Since the yield data indicated that detrimental effects were not measurable after 10 years, it is obvious that the soil can act as a sink and that applying excess manure to soil is probably still the least expensive and most effective means of disposal.

INFLUENCE OF LONG-TERM FERTILIZER APPLICATION ON SOIL QUALITY

H. H. Janzen

Nitrogen fertilizer applied at a rate of 45 kg/ha for 18 consecutive years to continuous wheat or fallow-wheat-wheat production systems promoted conservation of vital soil organic matter reserves. Fertilization increased organic N and C concentrations by approximately 14% relative to unfertilized treatments. In addition, application of inorganic N enhanced indigenous soil fertility by increasing the proportion of mineralizable, potentially available N.

Sustained productivity of prairie soils in western Canada depends on the conservation and replenishment of their organic matter reserves. According to some estimates, the grassland soils of western Canada have lost nearly 50% of the organic matter reserves initially present in the surface horizon. The reversal of this disturbing trend depends on the identification and implementation of agronomic practices that promote soil quality conservation.

Every year some 2.5 million tonnes of fertilizers, primarily carriers of nitrogen (N) and phosphorus (P), are applied to agricultural soils in the Prairie Provinces. Despite the

magnitude of these inputs and further projected increases in fertilizer applications, the impact of inorganic fertilizers on soil organic matter and long-term soil productivity has not been been fully elucidated. In recent years, some concern has been expressed regarding possible long-term injurious effects of inorganic fertilizer applications on soil productivity. A study was initiated to determine the influence of N and P application on total and mineralizable organic matter levels using soil sampled from an ongoing long-term crop rotation study initiated in 1912.

Surface soil samples were obtained from four treatments, a factorial of two N application rates (0 and 45 kg N/ha) and two P rates (0 and 20 kg P/ha), from each of two rotations, continuous wheat (W) and fallow-wheat-wheat (FWW). The N had been applied as ammonium nitrate for 18 consecutive years and the P had been applied for 13 years when the soil samples were taken in the fall of 1984.

Nitrogen fertilizer application significantly increased the levels of organic matter present in the surface soil. In both rotations, as illustrated for the W rotation (Fig. 1), organic C levels were increased by approximately 14% relative to levels observed in soil receiving no N fertilizer. Similar increases were observed in soil organic N concentrations (Fig. 2). These highly significant increases occurred after just 18 years, which is a short time interval in terms of soil development. Phosphorus application had no significant effect on organic C or N levels.

The increases in organic matter and soil N concentrations observed in N-fertilized soil can be attributed largely to larger inputs of organic substrates in the form of crop residues. By promoting higher yields, N fertilization increased the amounts of straw, roots, and possibly root exudates added to the soil. Since materials represent the primary source from which soil organic matter is derived, levels of organic matter and organically bound nutrients are directly linked to crop yield, provided that crop residues are returned to the soil. The absence of an effect of P fertilizer on soil organic

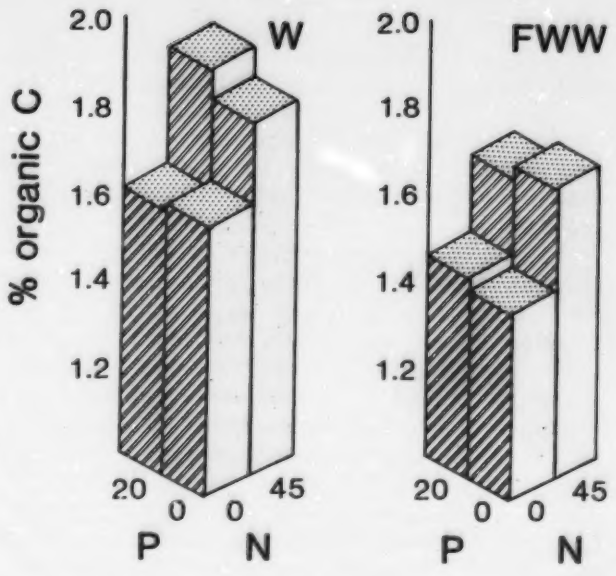


Fig. 1. Soil organic C concentrations as influenced by N and P application in two crop rotations.

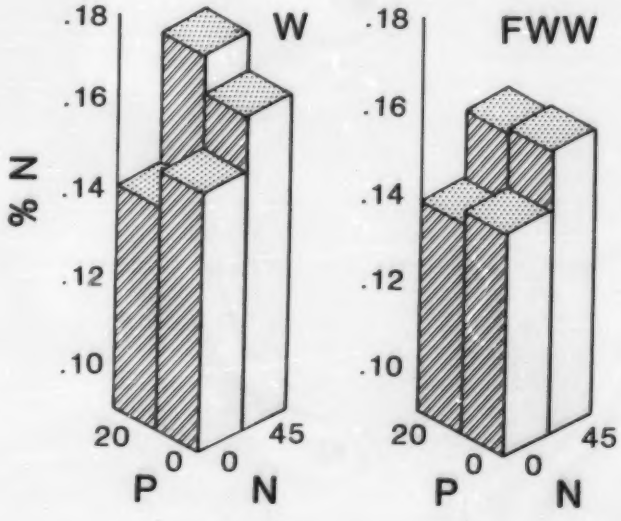


Fig. 2. Total soil N concentrations as influenced by N and P application in two crop rotations.

matter content is attributable to the high indigenous levels of plant-available P in the soil studied and, hence, the absence of an appreciable yield response.

From the standpoint of soil fertility, the levels of labile organic matter fractions (i.e., those which readily revert to plant-available forms via mineralization processes) are more important than total N and C concentrations. Application of inorganic N fertilizer increased the levels of mineralizable N even more than levels of total N. In the W rotation, the amount of N mineralized under standard conditions was 32% higher in soil that had received N fertilizer than in soil receiving no N fertilizer (Fig. 3). The corresponding increase in the FWW rotation was 23%. Nitrogen fertilization, therefore, has substantially increased the size of the potentially mineralizable N pool, which provides much of the crop N requirements.

Measurement of soil pH showed a slight decline (0.3 pH units) resulting from 18 years of N fertilizer application. This drop in pH does not pose a significant threat to soil productivity and may even be of some benefit since the soil is slightly calcareous.

The results of this study demonstrate a substantial benefit of N fertilization to soil quality. Not only did N fertilizer application contribute to the conservation and replenishment of organic matter levels in the soil, but it also enhanced the labile N pool within the organic matter, which is closely linked to short-term fertility. Thus, fertilization not only provides N for immediate crop consumption, but also contributes to the inherent fertility of the soil. By maintaining organic matter levels and organic matter quality through regular additions of moderate rates of N fertilizer, future reliance on higher inputs resulting from depletion of organic N reserves may be prevented.

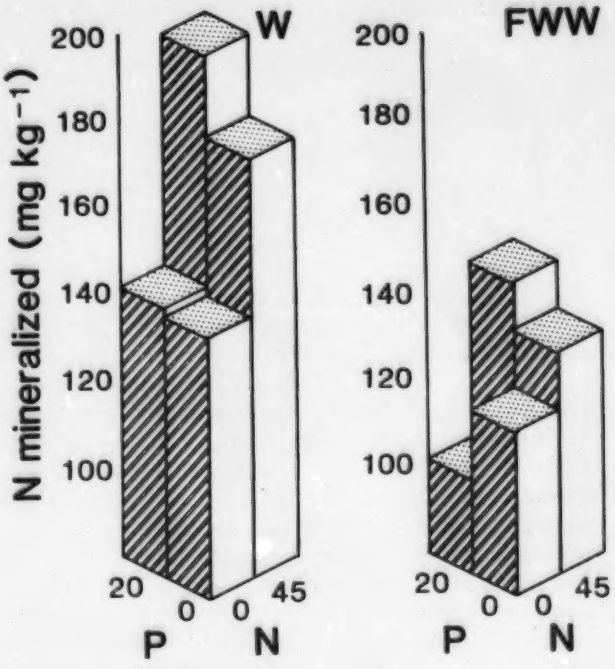


Fig. 3. Nitrogen mineralization during an 18-week period as influenced by N and P applications in two crop rotations.

NITROGEN FERTILIZER EFFICIENCY IS AFFECTED BY METHOD OF ADDITION

R. M. N. Kucey

Nitrogen fertilizer effectiveness was found to vary depending on the combination of fertilizer form, method of application, and time of addition.

Not all additions of nitrogen (N) fertilizers will have equal effects on crop yields. Under field conditions, the method of applying N can have as much or greater effect on crop yields as the form of N. Most of the N sold in western Canada is in the form of urea, ammonium nitrate, and anhydrous ammonia. At the present time, ammonium nitrate accounts for 15% of the market, while anhydrous ammonia and urea hold 45 and 40%, respectively. Interest in banding of N has raised questions with regard to the effectiveness of the various types of N fertilizers and the effectiveness of banded N relative to broadcast N. Another important aspect of fertilizer efficiency is the time of addition (spring vs. fall) and its effect on losses of N.

A series of field experiments was conducted in southern Alberta over four growing seasons on both irrigated and non-irrigated experimental sites. Ammonium nitrate, urea and anhydrous ammonia additions up to 120 kg N/ha were compared for effectiveness in increasing barley yields. Surface broadcasting of the two granular forms, ammonium nitrate and urea, was compared with banding (30-cm spacing, 15-cm depth) of the same fertilizers. All the combinations of fertilizer form and method of application were added in the spring of the growing season and compared with equal additions performed in the previous fall after the soil temperature had fallen below 5°C.

Comparisons of yield increases resulting from broadcast application of urea and ammonium nitrate in the spring are shown for irrigated land in Fig. 1. Broadcast ammonium nitrate was more effective than broadcast urea, except at the high levels of addition. The differences between the response curves are important because the ammonium nitrate line is very close to the N fertilizer recommendation curve. Thus,

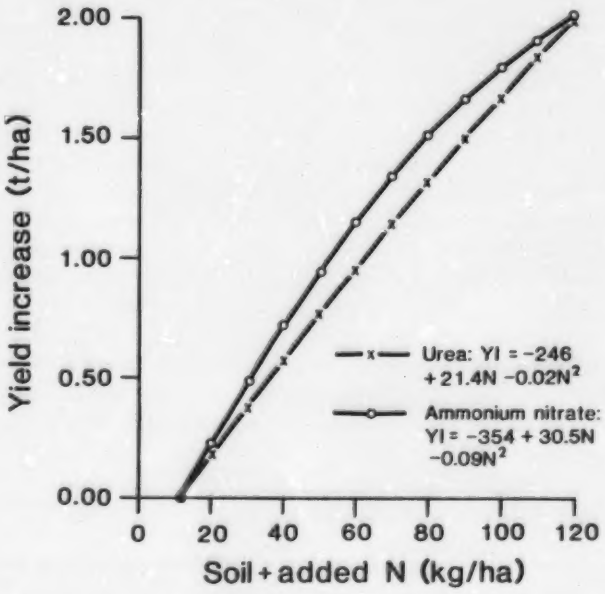


Fig. 1. Barley yield increases from spring-applied, broadcast N fertilizers in southern Alberta. YI = yield increase relative to unfertilized yields; N = soil test N + added fertilizer N.

if broadcast methods are used, particularly if fertilizer is not or can not be incorporated, then ammonium nitrate is the form with less potential for losses and hence greater effectiveness. If urea is to be used, greater amounts of N would be needed to achieve optimum yields. Under dryland conditions, differences between fertilizers were found to be minimal because water, not N, was the limiting factor to crop growth.

Another aspect of the research showed that if N fertilizers were banded 15 cm below the surface, no differences in effectiveness among the three forms of N were found. Consequently, anhydrous ammonia, urea, and ammonium nitrate resulted in the same yield. Furthermore, the yield increases

obtained were greater than those obtained with broadcast forms added at the same rates. The relative yields from N application by banding and broadcasting are shown in Fig. 2. If the spring broadcast curve is used for comparison, then the spring-banded curve clearly shows that yields can be increased by banding the same N rate. Conversely, decreased N additions if the N is banded can result in the same yield levels as a higher rate of broadcast N.

Figure 2 also shows the yields obtained from fall application of N. At low to moderate rates of N addition, little if any reduction in yield was observed relative to the spring-applied treatment. At higher levels of N addition, the fall curves tailed off. Care must be used in interpreting these curves because the data are from an experiment in which the fall-applied N was added very late in the season. Soil temperature at the time of N application was below 5°C. Earlier fall application can result in 20-30% losses of N before winter.

The results of this study have important implications for fertilization of southern prairie soils. First, if broadcast methods are used, ammonium nitrate should be used since it results in greater yields than equivalent rates of urea N. Second, banding of granular N or anhydrous ammonia can result in greater yields than equivalent rates of broadcast granular N. Lastly, fall application of N, if done after soil temperatures fall to 5°C, does not result in significant losses of N relative to spring-applied N in the southern part of the province. These facts can be used by producers to aid in selecting the most efficient fertilization system for their operation.

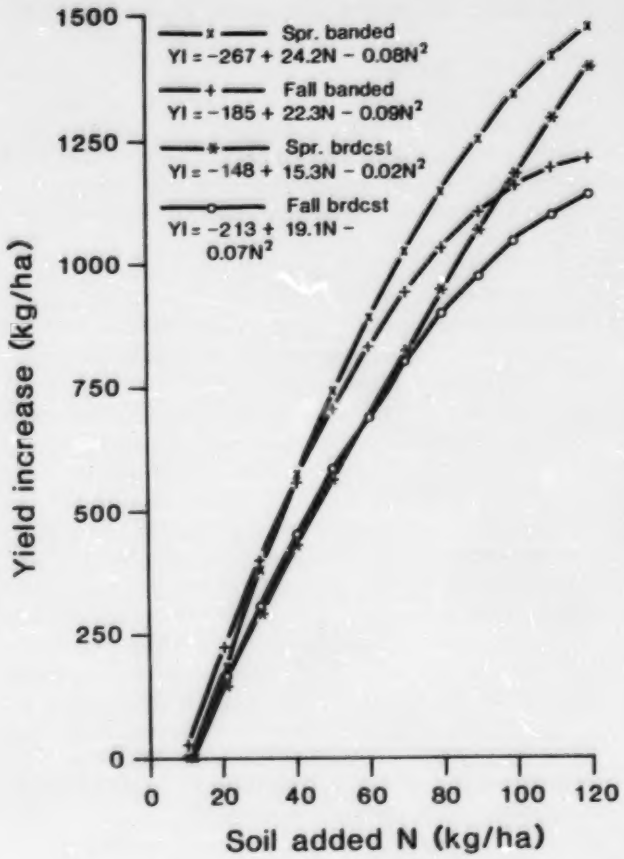


Fig. 2. Barley yield response to N fertilizer applied to southern Alberta soils. YI = yield increase relative to unfertilized yields; N = soil test N + added fertilizer N.

MYCORRHIZAL FUNGI INCREASE PLANT MICRONUTRIENT UPTAKE

R. M. H. Kucey

Mycorrhizal fungi were found to increase plant growth by increasing plant uptake of phosphorus, zinc, copper, and iron, and to indirectly increase plant uptake of manganese. Addition of excess phosphate fertilizers inhibits mycorrhizal fungi and may result in micronutrient deficiencies.

Addition of vesicular-arbuscular mycorrhizal (VAM) fungi to soils low or lacking in indigenous VAM has been shown to increase plant growth, primarily by increasing the uptake of phosphorus (P). Unfortunately, addition of P fertilizers has been reported to decrease the degree of root colonization by native and added VAM and has also been reported to induce micronutrient deficiencies in plants. This indicates that VAM may be involved in the uptake of plant nutrients other than phosphorus. For that reason, the effect of VAM on field bean dry matter production and phosphorus, zinc, copper, iron, and manganese uptake was determined under greenhouse conditions.

VAM inoculation resulted in increased plant dry matter production relative to uninoculated plants under conditions where the amount of soil available for root growth was varied (Table 1). As well, the plant dry matter production increased with increasing amounts of soil available to the roots. The proportional increase in dry matter production caused by VAM inoculation was 1.37X (+VAM/-VAM) for the 2000-g soil treatment and 1.19X for the 500-g soil treatment.

VAM were found to directly increase the uptake of P, Zn, Cu, and Fe by field beans in the experiments and to indirectly increase plant uptake of Mn. Manganese uptake was determined to be indirectly increased since the concentration of Mn in the plant tissues did not increase while the concentrations of P, Zn, Cu, and Fe did increase. The increase in nutrient uptake as a response to VAM inoculation decreased as the amount of soil available for rooting decreased.

This shows that the increased absorption of nutrients was primarily due to an increase in the absorptive surface area caused by the VAM hyphae extending outward from the roots, and that the increased area caused by the VAM was offset by having the roots in a smaller space. This also indicates that if nutrients are in sufficient supply, the effect of VAM will be minimal since the increased absorptive surface area would not be needed for adequate nutrient uptake.

Table 1. Effect of mycorrhizal fungi (VAM) on elemental composition of field beans.

Weight of soil (g)	VAM	Plant weight (g)	Plant elemental content (units/plant) P (mg)	Zn (µg)	Cu (µg)	Fe (µg)	Mn (mg)
500	-	5.51	13.3	75	18	643	1.31
	+	6.54	14.0	114	46	691	1.18
1000	-	8.19	16.0	137	120	812	2.21
	+	9.78	24.3	206	161	1096	2.35
2000	-	8.30	14.5	128	104	861	2.44
	+	11.4	26.2	224	186	979	3.19

Previous research conducted with prairie soils showed that addition of phosphate fertilizers to soils at recommended levels resulted in significant decreases in the colonization of roots by VAM (Fig. 1). This resulting decrease in VAM colonization may lead to micronutrient deficiencies in soils with marginal micronutrient availabilities. This effect would be most pronounced for crops without fibrous root systems, such as legumes, where the effect of VAM has been found to be greater than for cereal crops with finely branched root systems.

Indeed, a few cases of micronutrient deficiency have been reported for legumes in soils for which cereal crops show no deficiency. This finding may have important implications in the testing of soils for micronutrient availability, since these tests rely mostly on chemical indices of availability, and do not consider the biological aspects of soils. Soils high in available phosphorus and showing adequate levels of micronutrients may still result in plants with micronutrient deficiencies because of the effect of P on the mycorrhizal fungi.

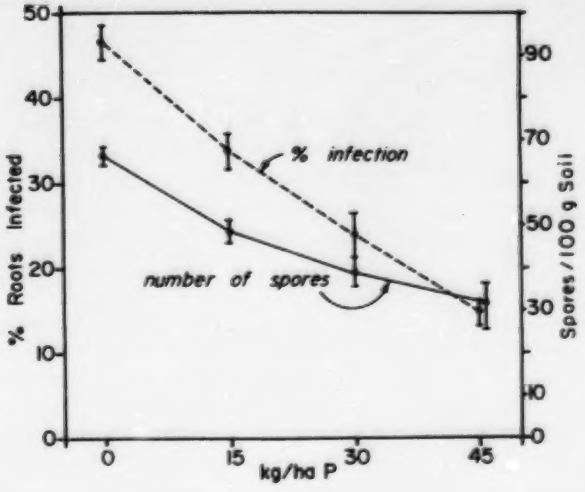


Fig. 1. Effect of added phosphorus on mycorrhizal root colonization and spore production on faba beans.

ESTABLISHMENT OF SAFFIRE SAFFLOWER AND MELROSE SAINFOIN ON A SALINE SEEP

G. J. Beke

Saffire safflower emerged earlier and appeared to be more salt-tolerant and less sensitive to plant water stress at the seedling stage than Melrose sainfoin. However, Saffire may not reach maturity in saline areas if it receives less than 50 mm of growing season precipitation.

Seedling establishment on former saline seep areas may be subject to a variety of environmental stresses including drought, crusting, soil salinity, and waterlogged subsoil. Drought causes low soil water potential, salts lower the osmotic potential of the soil solution, and specific ions may be toxic to germinating seeds and seedlings. Precipitation in southern Alberta generally peaks in the spring months, with 32% of the total annual precipitation occurring during May and June. However, throughout the growing season average evaporation from a free-water surface is nearly three times the mean precipitation. This moisture deficiency under dryland agriculture must be alleviated by supplementary water supplied from stored soil moisture. In southern Alberta, the soil water content generally decreases during the growing season and soil water may be unavailable for seedling growth. A field study was conducted to compare the establishment of Saffire safflower and Melrose sainfoin in relation to soil salinity and distance from subsurface drains.

The experiment was established on a recently (1978) drained saline seep area. The subsurface drainage system consisted of three lateral interceptor drains connected to a main drain, all composed of perforated plastic tubing. A replicated plot experiment, with the center of each 3 x 16 m plot situated above a lateral drain, included the specialty crops Saffire safflower and Melrose sainfoin. All seed was placed at a depth of about 2.5 cm. The sampling sites were selected on the basis of distance from plot center.

Shortly after crop emergence, the number of plants within a 1-m distance of row, centered at the specified site locations, were recorded. Recounts were made every two weeks throughout the growing season. Soil samples were taken at the specified sites in five of the 11 plots per replication shortly after the crops emerged and thereafter on a monthly basis for salinity and water potential characterization. Sampling was conducted at 0-5, 5-15, and 15-30 cm depth intervals. Total soil water potential was measured with a Wescor PR55 psychrometer microvoltmeter prior to air-drying of the samples. The electrical conductivity (EC) was determined on the saturation paste extract of the samples.

The average EC in the 0-30-cm depth was used to indicate the mean salinity level of the soil per site location for each sampling date. Mean total soil water potentials for the designated site locations were calculated according to sampling interval.

Saffire safflower seedlings emerged at an earlier date, more uniformly, and in greater numbers than those of Melrose sainfoin (Table 1). Emergence of both crops was best at the downslope plot location and poorest at the mid-plot location. The decrease in total soil water potential shortly after sowing had little influence on safflower germination, possibly owing to lower salinity levels (Table 2). Post-sowing precipitation did not appear to affect safflower germination but may have stimulated sainfoin germination. This was indicated by the late May increase in total soil water potential of the 0-5-cm soil depth to less than -1500 J/kg at two of the three locations. Similarly, the high precipitation in August resulted in increased sainfoin germination, while all safflower appeared to have germinated in the spring.

Table 1. Precipitation, mean safflower and sainfoin seedling numbers, and mean total soil water potential (SWP) in the 0-5 cm depth for three plot locations.

Date	Precip. (mm)	Upslope			Midslope			Downslope		
		No. saff. plants	No. sain. plants	Total SWP (J/kg)	No. saff. plants	No. sain. plants	Total SWP (J/kg)	No. saff. plants	No. sain. plants	Total SWP (J/kg)
May 14	n.d.[1]	0.0	0.0	-389	0.0	0.0	-470	0.0	0.0	-444
21	7.6[r]	8.9	0.0	-556	6.2	0.0	-3412	12.4	0.0	-5676
June 2	13.7	8.9	6.6	-1235	7.1	5.9	-1294	12.4	11.8	-1618
21	6.2	8.9	7.8	-5400	7.1	7.7	-6000	12.4	9.4	-5235
28	1.0	8.9	7.8	-5286	7.9	8.8	-5412	10.1	8.4	-4941
July 15	0.0	8.9	5.3	-5600	10.6	8.8	-5676	9.4	8.4	-5412
30	10.2	6.7	5.3	-5971	7.6	5.6	-6000	8.1	5.6	-5941
Aug. 28	89.9	6.7	8.3	-1287	7.6	5.9	-706	8.1	8.3	-917
Sept. 3	0.0	6.7	8.3	-1278	7.6	5.9	-222	8.1	8.3	-389

[1]No data.

Table 2. Mean salinity (dS/m) in the 0-30 cm soil depth for three plot locations.

	Upslope	Midslope	Downslope
May 14	8.8	4.4	8.4
21	4.6	3.8	5.4
June 2	8.0	6.0	11.4
21	11.5	8.0	11.4
28	9.6	8.0	11.4
July 15	10.2	8.1	12.2
30	11.4	8.1	12.9
Aug. 28	10.4	8.6	10.8
Sept. 3	11.4	10.2	12.9

The number of seedlings per meter of row generally decreased through the summer (Table 1). This was accounted for by lack of substantial precipitation and stored plant-available soil moisture in the 0-30-cm depth. As well, the salinity of the soil solution increased until the onset of rains in mid-August. Soil water potential in the 5-15-cm depth decreased below the wilting point by mid-July and in the 15-30-cm depth it decreased to around the wilting point by early August. The increase in soil water potential with sampling depth through the growing season indicated the presence of plant-available water at depth provided that the roots had extended to that depth. However, by early August the safflower plants were showing signs of stress, which disappeared following the mid-August precipitation. More seedlings of both crops were established at the downslope plot location in spite of lower soil water potentials in the 5-15 and 15-30 cm depths and higher salinity than at the other site locations. This may be related to more static groundwater levels at the downslope site as the subsurface drain that controls the water table at this location is situated downslope from it. Hence, the downslope location is at a greater distance from the effective subsurface drain than the other sites studied.

These results show that Saffire safflower is better able to establish on saline soils with subsurface drainage than Melrose sainfoin, when both crops are sown in the spring. However, growing season precipitation of less than 50 mm would be insufficient for Saffire safflower to reach maturity on this saline soil even though the soil moisture reserves in the spring were very good. As determined from the distance of a crop from subsurface drainlines, better site drainage results in lower soil salinity but poorer crop performance.

EFFECTS OF TILLAGE AND CROP ROTATION ON PHYSICAL PROPERTIES OF A CLAY LOAM SOIL

C. Chang and C. W. Lindwall

After 10 years of winter wheat production, tillage and crop rotation had no significant effects on most soil physical properties measured in the surface 30 mm and below the tillage zone (90-120 mm). The only significant effects of tillage treatment were observed at 30-60 mm depth. Although results indicated that this clay-loam soil under zero till had lower hydraulic conductivity, higher bulk density, and lower plant-available water-holding capacity than soil under conventional tillage, none of the soil properties approached the levels that would limit crop production.

Conventional tillage systems have been effective for economic and reliable weed control, for burying crop residues, for seedbed preparation, and for mixing fertilizer and herbicides into the soil. But conventional tillage is often the cause of soil erosion, excessive soil moisture loss, and deterioration of the soil structure. Recent results in southern Alberta indicate that minimum and zero tillage practices offer promising alternatives to conventional tillage. They reduce soil erosion losses, conserve more soil moisture, and save time and energy compared with conventional tillage systems. Yields of cereals, particularly winter wheat, with zero tillage have been equal to or greater than those grown with conventional tillage. However, the long-term effects of zero tillage management on soil physical properties have not been determined in this region.

Soil physical properties may have direct or indirect effects on plant growth. Soil water availability is a dominant factor affecting plant growth. Available oxygen, root penetration resistance, and soil temperature as affected by water content are indirect factors. Increasing the water content decreases aeration, which is undesirable, but also decreases root penetration resistance, which is desirable. Soil bulk density and pore size distribution affect the relationship between plant available water and both soil aeration and root penetration resistance.

The objective of this study was to examine the long-term effect of conventional tillage and zero tillage on the soil-water related properties such as saturated hydraulic conductivity (HC), saturation percentage (SAT), plant-available water-holding capacity, porosity of large pore size, and soil bulk density of a clay loam soil at tillage zone and immediately below.

Research plots were established in 1976 on a clay loam soil at Lethbridge. Three winter wheat rotations: continuous winter wheat (WW); winter wheat-barley-fallow (WBF) and winter wheat-fallow (WF) were established.

Each rotation included tillage with a heavy-duty cultivator (cultivated to 80 mm or less) and zero-till (ZT) treatments. In all three crop rotation treatment, the heavy-duty cultivator was used for the initial seedbed preparation and the rod weeder and packer combination was used for the final seedbed preparation. The most suitable herbicides, such as Roundup (glyphosate), were used to control weeds on chemical fallow and for weed growth prior to seeding on all ZT treatments.

Two undisturbed soil cores 5.35 cm in diameter were collected from three replicates of all treatments at depths of 0-30, 30-60, and 90-120 mm in the spring after seeding in 1985. Soil bulk density, water retention at moisture potentials of 0, -5, -10, -20, -30, -500, and 1500 kPa and saturated hydraulic conductivity were determined. Plant-available water-holding capacity (PAWHC) is the soil water held between the water potentials of -20 and -1500 kPa and porosity of large size pores (LAP) is the percent volume of air-filled pores at a soil water potential of -20 kPa.

The soil physical properties of HC, SAT, and LAP at the 30-60 mm depth were significantly different between the tillage treatments (Table 1). At that depth, HC was 52% higher, SAT was 8% higher, and LAP was 23% higher with cultivation than with ZT. The effects of tillage on the other soil properties at this depth and all properties at the other two depths were not significantly different. However, there was a general trend for SAT, PAWHC, and LAP to be lower on ZT plots than on cultivated plots at all depths. The HC was lower with ZT than with cultivation at the 30-60 and 90-120 mm depths but not at the 0-30 mm depth. The BD was also lower on ZT plots than on cultivated plots but the differences were small and less than 0.07 kg/m^3.

In general, the soil from the winter wheat-fallow rotation had higher HC, SAT, PAWHC, and LAP but lower BD than the soil from the other two crop rotations, with the exception of the soil from depth 1 (Table 2). However, differences between crop rotation treatments for a given depth were small. Overall, none of the soil physical properties measured were significantly different as a consequence of the different cropping rotations (Table 2).

The cultivated treatment was only tilled to a depth of 80 mm or shallower. Therefore, the soil was not disturbed below that depth. Soil properties at the 90-120 mm depth determined in this study were not significantly affected by tillage treatment after 10 years. The heavy traffic associated with tillage did not seem to compact the soil at the 90-120 mm depth. Hardpans are usually formed under relatively wet soil conditions. However, in this study, the soil moisture content was usually below field capacity (moisture potential >-20 kPa) during the tillage operation.

The effects of tillage treatment on soil physical properties in the surface 30 mm were minimal. Freezing and thawing effects during the winter months in southern Alberta seemed to minimize the cumulative soil compaction effects often associated with long-term zero-till practices. The self-mulching characteristics of this calcareous clay loam soil were also beneficial in this regard. Tillage loosened the soil, but

Table 1. Effects of tillage on physical properties[1] of a clay-loam soil.

Treatment[2]	HC (cm/hr)	BD (t/m^3)	SAT (%)	PAWHC (%)	LAP (%)
			Depth 1 (0-30 mm)		
ZT	2.023	1.09	60.62	12.80	30.92
HDC	1.799	1.16	60.65	13.21	31.55
			Depth 2 (30-60 mm)		
ZT	0.481*	1.37	51.57*	9.60	19.65*
HDC	1.009	1.34	56.12	9.84	25.38
			Depth 3 (90-120 mm)		
ZT	0.876	1.33	52.75	10.11	19.23
HDC	1.276	1.34	54.79	10.12	22.41

[1]HC = hydraulic conductivity; BD = bulk density; SAT = saturation percentage; PAWHC = plant-available water-holding capacity; LAP = large pores.

[2]ZT = zero-till; HDC = heavy-duty cultivator.

*Values within a column for a given depth are significantly different (P=0.05).

Table 2. Crop rotation effects on soil physical properties[1].

Rotation	HC (cm/hr)	BD (t/m^3)	SAT (%)	PAWHC (%)	LAP (%)
			Depth 1 (0-30 mm)		
WW[2]	1.883	1.06	60.47	13.76	30.73
WF	1.861	1.12	61.94	12.34	32.64
WBF	1.989	1.18	59.49	12.92	30.34
			Depth 2 (30-60 mm)		
WW	0.686	1.36	54.00	9.41	23.13
WF	0.818	1.34	55.58	9.98	24.73
WBF	0.773	1.36	51.97	9.77	19.70
			Depth 3 (90-120 mm)		
WW	1.378	1.34	54.76a	10.06	22.44a
WF	1.342	1.29	54.89a	10.34	22.75a
WBF	0.508	1.36	51.66b	9.95	17.27b

[1]HC = hydraulic conductivity; BD = bulk density; SAT = saturation percentage; PAWHC = plant-available water-holding capacity; LAP = large pores.

[2]WW = continuous winter wheat; WF = two-year rotation (winter wheat-fallow); WBF = three-year rotation (winter wheat-barley-fallow).

a,b Values followed by the same letter are not significantly different (P=0.05).

the final seedbed preparation with a rod weeder and packer combination compacted the soil surface. Therefore, the bulk density of the surface soil receiving conventional tillage was greater than that of the soil under zero-till. Crop rotation had no significant effect on any of the soil properties at the upper two depths and only a minor effect on properties at the deeper depth.

The effects of tillage on soil physical properties such as HC, SAT, and LAP were more apparent at the depth of 30-60 mm than at the other depth intervals. At this depth, the soil receiving conventional tillage was mechanically loosened by the heavy-duty cultivator and the final seedbed preparation with the rod weeder and packer combination did not seem to recompact the soil at this depth. Therefore, the conventionally tilled plots had higher hydraulic conductivity, lower bulk density, and higher saturation percentage and, to a lesser degree, higher porosity of large pores and available water-holding capacity.

After 10 years of winter wheat production there were no significant differences between tillage treatments on soil physical properties such as HC, BD, PAWHC, and LAP at the surface (0-30 mm) and below the tillage zone (90-120 mm). The only significant effects of tillage treatment were observed at 30-60 mm. Similarly, crop rotation had very little effect on most soil physical properties. Ten years of zero-tillage and continuous cropping resulted in slightly lower HC, higher BD, and lower PAWHC than observed with conventional tillage but none of the soil properties approached the values that would adversely affect crop production.

A COMPARISON OF METHODS TO DETERMINE POTENTIAL EVAPOTRANSPIRATION IN SOUTHERN ALBERTA

B. Grace

Eight commonly used methods of calculating potential evapotranspiration were compared under different climatic conditions at the Lethbridge Research Station. Under conditions of low wind speed and moderate humidities the methods produced similar results. However, under dry, windy conditions estimates of PE differed widely. Equations that require the use of wind and humidity data as well as temperature and radiation data are recommended for use in computer simulation models in the chinook-dominated semi-arid climate of southern Alberta.

In agriculture the use of computer models to simulate field conditions is widespread. Most models currently used on an operational basis in southern Alberta for soil moisture evaluation, crop yield prediction, irrigation scheduling, etc. employ the concept of potential evapotranspiration (PE) as the driving function for the calculation of field evaporation.

PE may be defined as the evaporation from an extended surface of short green crop that fully shades the ground, exerts little or negligible resistance to the flow of water, and is always well supplied with water. There are several methods of calculating PE and the methods generally yield similar though not identical results. The more common methods in use in western Canada include some adaptation of the Priestly-Taylor formula, Baier-Robertson formulae, and the Jensen-Haise equation. Real evapotranspiration cannot exceed and is usually less than PE. Similarly, evaporation from a Class A Evaporation Pan is always greater than PE. The reasons for these differences are best explained by reference to the conditions imposed by the definition of PE and an analysis of the reality of these conditions. However, under the influence of the unique, chinook-dominated climate of southern Alberta, a comparison of the various methods of calculating PE has not been made.

Climatic data gathered at the Lethbridge Research Station for 1983, 1984, and 1985 were used to calculate PE for each day of the growing season by eight different methods. The equations chosen for comparison included those of Penman, Jensen-Haise, Doorenbos-Pruitt, Priestly-Taylor, the Selirio adaptation of the Priestly-Taylor equation, the Jury-Tanner adaptation of the Priestly-Taylor equation, and two Baier-Robertson equations. Climatic data from a 21-day period in June 1984 were arbitrarily selected for the comparison of PE methods.

Class A pan evaporation is the only measurement of evaporation made on a regular basis. Other parameters such as temperature, radiation, wind speed, and relative humidity all affect the magnitude of pan evaporation. Analysis of daily PE values from 1983-1985 indicated that formulae based on only radiation and temperature, i.e., Jensen-Haise, Priestly-Taylor, and Baier-Robertson, were the most poorly correlated to pan evaporation (R^2 of 0.43-0.67). Equations which required humidity and/or wind data were better correlated with R^2 values ranging from 0.67 for the Penman formula 0.96 for the Doorenbos-Pruit equation.

Under conditions of low wind (< 500 km wind run) and moderate relative humidities (45% to 85%), calculated values of PE ranged from 50 to 80% of pan evaporation. This is illustrated in Fig. 1 for the time period of June 10 to June 20 1984. Cool temperatures, high humidities, and precipitation (24.4 mm on June 21), had the effect of depressing pan evaporation and calculated PE values on the 20, 21, and 22 of June. However, under conditions of high wind (>500 km wind run) and lower humidities (< 40%), values of PE varied widely from 15 to 60% of pan evaporation. For example, the dry (35% RH) and windy (1126 km wind run) day of June 30 resulted in calculated PE of from 2.6 mm to values more than three times as great (10.8 mm) as shown in Fig. 1.

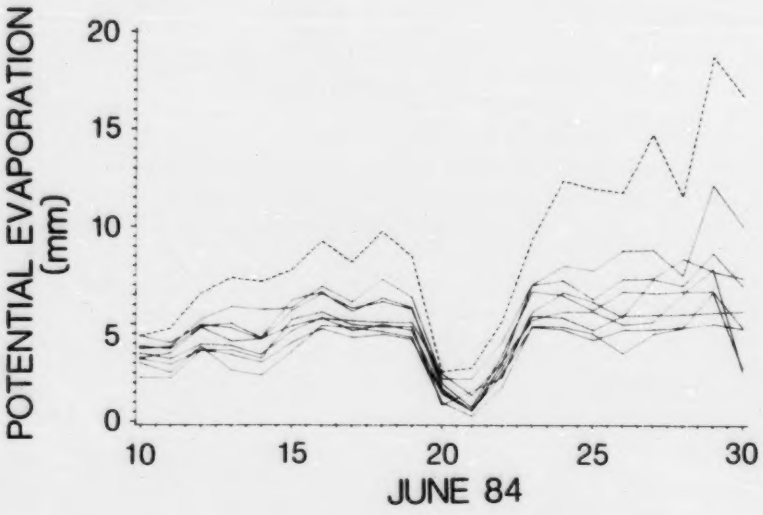


Fig. 1. Measured class A pan evaporation and calculated daily potential evapotranspiration from eight different methods for June 10 to June 30 1984.

Many of the crop and soil moisture simulation models accumulate PE totals to estimate the total evaporation from a site during a given period of time. This information is then used to make management decisions. The accumulated PE for the 21 days examined here ranged from a low of 75.0 mm as calculated with the Jensen-Haise method to a high of 138.1 mm with the Doorenbos-Pruit formula (Table 1). Discrepancies this large could have serious consequences for such applications as irrigation scheduling.

Some of the computer simulation models currently in use on an operational basis in the semi-arid windy environment of southern Alberta may be signficantly underestimating evaporation by employing equations that do not account for advective energy input. PE equations that require humidity and wind data more correctly simulate real conditions in the chinook-dominated climate of southern Alberta.

Table 1. Potential evapotranspiration for June 10 to June 30 1984.

	Daily mean	Daily maximum	Daily minimum	Accumulated (21 days)
Pan Evaporation	8.8	18.8	2.2	194.4
Penman	4.2	5.7	0.6	93.3
Jensen-Haise	3.4	6.7	0.3	75.0
Baier-Robertson I	4.5	7.9	1.4	98.3
Baier-Robertson II	4.5	8.7	0.0	99.1
Priestly-Taylor	5.1	6.8	0.7	112.3
Selirio Adaptation	3.8	5.1	0.6	83.2
Jury-Tanner Adaptation	5.4	8.4	0.6	119.5
Doorenbos-Pruitt	6.3	12.2	1.7	138.1

DEPTH CRITERIA FOR SUCCESSFUL FIELD INSTALLATION OF MOLE DRAINS

T. G. Sommerfeldt and C. Chang

In a field study of mole drain installation in a clay loam soil, with soil moisture content at near field capacity and higher, the critical depth was at 50 cm. The apparent performance of mole drains was not affected by depth of installation, below the critical depth to 90 cm, although literature values indicate otherwise. Segments of the smeared surface of the mole were pulled away by the moling bullet, leaving ports for water entry into the drain. Soil compaction at the bottom of the drain, which is the zone for most water entry into the drains, was insignificant, allowing saturated flow similar to that of the surrounding soil.

Many saline and waterlogged fine-textured soils in southern Alberta could benefit from inexpensive mole drainage. In a laboratory study, the most effective drains were shown to be in soils with a clay loam or finer texture and a soil water content that exceeded 50% of field capacity during installation. In a subsequent field study with a clay loam soil and three water regimes, it was concluded that mole drains would perform well in this soil, when installed below the critical depth.

Critical depth is that depth at which the soil does not fracture to the surface during installation of mole drains. The literature indicates that smearing, which inhibits water entry into the drains, can occur along the perimeter of moles installed below the critical depth. Nevertheless, the most stable moles are formed when installed below the critical depth.

In a field study, drains were installed at depths of 50, 70, and 90 cm in a clay loam soil to verify whether a zone of compaction would develop around the mole to interfere with water flow into the drain. The soil was not flooded (D), or flooded one week prior (F1) to installation, or flooded one day prior (F2) to installation of the drains.

The critical depth for this soil was found to be at about 50 cm.

Stable moles were formed in all water regimes, but water treatments affected the conditions of the mole and the fracturing of soil above the mole, especially in the 0 to 40-cm depth. Because of the shallow water table, at 1.2-1.5 m depth, water treatment effects on the water content of the soil below 60 cm were small.

The bullet caused a smear on the perimeter of the moles, which was greatest in the moles of the F2 treatment and least in the D treatment. Within each water regime, sections of the smeared perimeter, 5-10 mm deep, had been pulled away by the bullet, leaving areas of exposed unsmeared soil. The frequency and size of these areas decreased as the amount of smear increased.

Visible fracturing of the soil above the drains was affected by depth of installation as well as by water treatment. Soil fracturing started at the sides of the moles installed at 50 cm (the critical depth) and extended upward to the ground surface, fanning out with distance. The width of the fan was greatest for the D water treatment and least for the F2 treatment. With the 70-cm-deep moles, fracturing began at the top of the moles and extended upward to the surface, fanning out with distance. The angle of the fan was smaller than that of the 50-cm-deep moles. For the 90-cm-deep moles, lateral fracturing, where it occurred, started at a depth similar to that of the 70-cm-deep moles, but the angle of the fan was small or non-existent, depending on the water treatment.

At depths of 50 and 70 cm the bulk densities (BD) of the soil to the side of and above the moles were smaller than those below the center of the moles, where BD was not significantly different from the undisturbed soil. For the

90-cm-deep moles the greatest BD was at the side of the mole, and the smallest was at the bottom, where it was similar to that of the undisturbed soil. The BD, at all depths and water treatments, varied with distance from the mole, depending on the direction, and on the depth of the drain. Most often there was a zone of compaction at a distance of 35 mm from the edge of the mole. The smallest bulk densities, as affected by water treatment, were generally in the soil that had been flooded one week before the drains were installed (F1) while the largest BD was in the soil that had not been flooded (D). The amount of reduction of BD with distance was greatest with the D treatment and least with the F2.

Compaction of the soil around the mole by the bullet, although significant, appeared to be unimportant. The reduction in porosity of the soil relative to that of the undisturbed soil was small, especially around the bottom portion of the moles, where most of the water supposedly enters the drains.

Water entry into moles installed at 50 to 90 cm should not be a problem in clay loam soil, as long as the soil is sufficiently wet to be cohesive during installation. The drag between the bullet and the soil is sufficient to pull away segments of the smeared skin, leaving areas of unsmeared soil through which water can easily enter the drains. Thus, entry of water into the moles should not be restricted by compaction or smear, when moles are installed within this depth range.

WATER QUALITY IN SOUTHERN ALBERTA IRRIGATION CANALS

J. R. Allan

Aquatic vegetative growth in southern Alberta irrigation canals is related to silt loading. The deposition of excessive amounts of phosphorus and organic matter-rich soil from eroded canal banks can provide habitats for root, submerged aquatic plants. Rehabilitation of canals should proceed from the top end of the system down, lining canal banks with crushed rock or stone riprap.

Excessive growth of aquatic vegetation is a visible problem in irrigation delivery systems but this is only a symptom of a deeper, more serious problem. Research on slow-moving (2500 cfs) supply canals in southern Alberta has shown that less than 0.2% of the water in the canal is silt. However, the total silt can reach up to 18 tonnes per hour (432 t/day) when examined over the long term. While most of this silt moves through the canal system, it can and will settle out when it reaches the quiet waters of on-stream storage reservoirs. The silt, which comes from surface runoff, contains nutrients that stimulate the growth of rooted submerged aquatic weeds. As agriculture strives for maximum crop production through the use of fertilizers and intensive agricultural practices, the need to prevent erosion and the subsequent silt loading and nutrient enrichment of our irrigation canals becomes imperative.

Soil fertility studies have shown that the key plant nutrient, phosphorus, is generally "locked" in the upper 15-30 cm of the soil profile. However, this soil layer is the first to be eroded

from the field by wind and water. The grass-covered canal banks are also rich in phosphorus and organic matter. These are the first to be washed into the canal during the spring snowmelt and heavy spring rains. As little as 1.5 kg of phosphorus in surface runoff from a 10-ha field produces enough nutrients for the growth of half a tonne of filamentous algae in 60 days.

Rehabilitated and newly constructed irrigation canals that are lined with crushed rock and pit-run gravel (Fig. 1) help to stabilize the canal banks. This also creates an environment that generally prevents the establishment of aquatic weeds. However, the introduction of material from old or unlined canal banks upstream can introduce sufficient silt to enable shallow-rooted aquatic plants (Small-leaved Pondweed, Potamogeton pusillus, and Horned Pondweed, Zannichellia palustris) to become established. Once established, these shallow-rooted plants slow up the movement of water and stimulate the deposition of additional nutrient-rich silt. Left unchecked, the new canal can become weed-infested and silt-filled (Fig. 2) in three years.

Water quality data from the upper Oldman River watershed and from prairie rivers and irrigation canals show that the water leaving the mountain watersheds is of the highest quality. The spring snowmelt and seasonal rains have a flushing effect in the main rivers and tributaries. However, once the water is slowed by the storage reservoirs, the silt begins to settle out and rooted aquatic plants begin to appear. The developing weed beds also offer a source of potential seeds for downstream propagation of additional weed beds.

In irrigation supply canals where silt reaches levels of 1000-1685 mg/L (0.1-0.2% of the water), this silt settles to the bottom of the canal and aggressive aquatic weeds begin to spread rapidly by runners, underground rhizomes, apical buds and fragmentation. One pondweed seed is capable of producing tens of thousands of runners, tubers and seeds in a single growing season if a nutrient-fertile silt bed is available.

Fig. 1. An ideal canal with rock riprapping, no visible bank erosion.

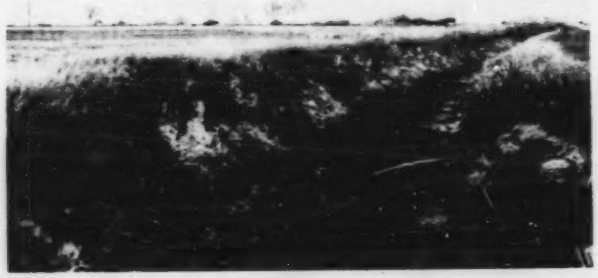


Fig. 2. Badly eroded canal banks with silt and soil deposited in the canal bottom, where rooted aquatic plants will become established.

Research at the Lethbridge Research Station has shown that the silt loading of irrigation water must be controlled. Canal banks must be lined with crushed rock and riprap. Canal rehabilitation must occur at the top end of the system and progress down the system. Erosion and surface runoff from old canal sections can destroy a rehabilitated canal section in three years through silt and organic matter deposition on and amid the gravel bed.

AQUATIC PLANT POPULATIONS IN IRRIGATION CANALS IN SOUTHERN ALBERTA

J. R. Allan and S. Smoliak

Aquatic plant species of the major irrigation canals in southern Alberta have been determined and related to water depth, flow velocity, and depth of hydrosoil in individual canals. This information is necessary for effectively developing mechanical, chemical, and biological control procedures for the implementation of an Integrated Aquatic Plant Management Program. Identification of species composition and various plant associations is necessary for future development of an aquaculture industry.

Excessive rooted submerged aquatic vegetative growth is a serious problem in irrigation delivery systems on the Canadian Prairies. Over 12,500 km of primary, secondary and on-farm irrigation and drainage canals are infested with unwanted algae and aquatic plants. These infestations can reduce delivery efficiencies by up to 91% of design capacity. Field surveys at the Lethbridge Research Station have identified a number of aquatic plant infestation characteristics which will enable implementation of an effective Integrated Aquatic Plant Management Program.

Large supply canals with water depths of 3 m or more are infested predominantly with pondweeds (Table 1). These canals have the highest silt loading and have very fine, organic matter-rich hydrosoil in the canal bed. They offer a minimum of 30 cm of hydrosoil depth for the overwintering tubers, which are the major asexual means of reproduction of the pondweeds.

Medium-size canals have a greatly reduced silt loading and have less rich hydrosoil. The major aquatics are listed in Table 1.

Table 1. Aquatic plants occurring in southern Alberta irrigation canals.

Species	Canal size and flow rate Large >1000 cfs	 Medium 350-1000 cfs	 Small 50-350 cfs
Giant Pondweed (Potamogeton vaginatus)	x		
Sago Pondweed (Potamogeton pectinatus)	x	x	
Flat-stemmed Pondweed (Potamogeton zosteriformis)	x		
Richardson's Pondweed (Potamogeton richardsonii)	x	x	x
Narrow-leaf Plantain (Alisma gramineum)		x	x
Small-leaved Pondweed (Potamogeton pusillus)		x	x
Northern Water Milfoil (Myriophyllum exalbescens)			x
Variable-leaf Water Milfoil (Myriophyllum heterophyllum)			x
Fries Pondweed (Potamogeton friesii)			x
Horned Pondweed (Zannichellia palustris)			x

Overwintering of the above aquatics is by tubers located shallowly (less than 15 cm) in the hydrosoil or, in the case of the small-leaved pondweed, by overwintering buds at the apical tips.

Small canals have almost no silt loading. The water is clear and solar radiation readily penetrates to the canal bed. The slower moving water allows more delicate-leaved aquatic plants to become established (Table 1).

Further differences are found according to the type of canal bed (fine silt, coarse sand, small gravel, or pit-run gravel). While no definite pattern has been established, generally the shallow rooted aquatics (small-leaved pondweeds, horned pondweed, Fries pondweed) become established in canals with 5-10 cm of silt over or between gravel in slow-moving canals.

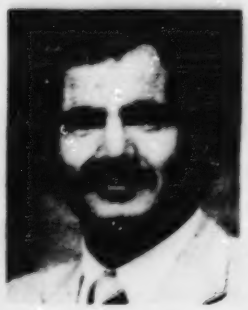
On-stream storage reservoirs contain a much more diverse population (in order of relative contribution to the total population) than do delivery systems: Richardson's Pondweed, Canada Waterweed (Elodea canadensis), Sago Pondweed, Northern Water Milfoil, Flat-stemmed Pondweed, Small-leaved Pondweed, Coontail (Ceratophyllum demersum), White Water Buttercup (Ranunculus aquatilis), Water Smartweed (Polygonum natans), Floating-leaved Pondweed (Potamogeton natans), and Duckweed (Lemna minor).

Therefore, on-stream storage reservoirs, while critical to constant water supply, will always offer a constant potential source of aquatic infestations for the irrigation delivery canals. Total vegetation control in these reservoirs is never desirable or feasible and the populations must be manipulated to cause a minimal amount of interference with water delivery.

This information is critical for determining the most effective mechanical, chemical, biological, or nutrient limitation technique for the implementation of an Integrated Aquatic Plant Management Program to control the specific problem plants without damaging the aquatic environment. A general knowledge of the diversity of aquatic populations in the various irrigation canals also will enable us to investigate possible biological procedures and the potential for establishing an aquaculture industry in our irrigation canals.

Aquaculture will enable us to use the irrigation canals to grow aquatic organisms that control excessive and undesirable vegetation and in turn are marketed to generate revenue for maintenance of the canal system.

MICROCOMPUTER-CONTROLLED IRRIGATION MANAGEMENT MODEL



M. Foroud

A user-friendly irrigation model has been developed for microcomputers which can assist irrigation farmers in improving the timing and quantity of irrigation. Also, it can be linked with irrigation system models to provide water demand guidelines for coordinating flow in irrigation distribution canals and turnouts to obtain greater efficiency.

Irrigation is potentially the most effective means of increasing food production. It is recognized that optimum irrigation results in the highest yields, but the common questions of "how much" or "how little" irrigation and "how many times" to irrigate to obtain maximum yields have not been answered by the conventional irrigation management strategy. An effective irrigation management system should be able to determine the balance between the water input by irrigation and/or rainfall, the soil moisture reservoir and crop use, surface evaporation, seepage, and deep percolation. Many parameters including weather, crop, soil, and management are important in developing an effective irrigation management program. The relationships between these parameters, complex in themselves but simple to apply in a computer model, enable rapid monitoring of the soil moisture status in the field for irrigation forecasting. The main objective of using a microcomputer-based irrigation management model is to improve the irrigation water management technique and to encourage more efficient use of existing irrigation water supplies.

The soil is an important reservoir of water for crop use. The maximum plant-available water is the difference between the maximum amount of water that can be held in the rooting zone after free drainage (field capacity) and the amount remaining after plants grown on the soil wilt and do not recover (wilting point). Since moisture is withdrawn from the available water stored (AVM) by evapotranspiration, a safe withdrawal must be defined and preassigned to prevent the moisture stress that reduces the crop yield. This safe withdrawal is termed allowable depletion (DPA). As moisture is withdrawn, less water will remain available to the crop.

The numerical value of the remaining available water (AVW) varies from day to day depending on the rainfall and/or irrigation input, if any, and evapotranspiration withdrawal. When moisture is readily available, for example after a significant rainfall or irrigation, it is withdrawn at a potential evapotranspiration (ETP) rate. However, water is usually limiting and moisture is therefore withdrawn at a rate less than ETP rate (ET). The determination of ET requires development of a crop curve coefficient (K_c) which is the ratio of ET to ETP. Neither ET nor ETP can be measured conveniently but they can be estimated from evaporation measured with any of several evaporimeters or calculated from meteorological data. K_c represents the combined relative effects of the resistance of water movement from the soil to the various evaporating surfaces and the resistance to the diffussion of water vapor from the surface to the atmosphere.

Table 1 represents the mean crop coefficients for a number of major crops in southern Alberta. The data in this table have been determined from the average ET curve for each crop and the average ETP curve. The average ET curve for one crop and the average ETP for southern Alberta are shown in Figs. 1 and 2, respectively. The mean crop curve when adjusted for soil surface wetness and the soil moisture level yields the crop curve coefficient, K_c, which can be used to calculate the variable ET.

Table 1. Coefficients of third degree polynomial equation[1] for the average crop curve, K_c, for southern Alberta.

Crop name	C_1	C_2	C_3	C_4
Alfalfa	-9.689E+00	1.555E-01	-7.157E-04	1.056E-06
Grass	-1.003E+00	-2.547E-03	1.722E-04	-5.494E-07
Wheat	1.517E+01	-3.278E-01	2.261E-03	-4.858E-06
Oats	2.718E+01	-5.373E-01	3.457E-03	-7.093E-06
Barley	3.292E+01	-6.612E-01	4.330E-03	-9.101E-06
Flax	2.419E+01	-4.686E-01	2.959E-03	-5.957E-06
Rape	2.973E+01	-5.760E-01	3.650E-03	-7.424E-06
Peas	4.624E+00	-1.213E-01	9.544E-04	-2.190E-06
Sugar Beets	-8.228E-01	-1.737E-02	2.586E-04	-6.406E-07
Potatoes	4.177E+00	-9.233E-02	6.538E-04	-1.360E-06
Corn	1.224E+01	-2.223E-01	1.311E-03	-2.420E-06
Beans	2.066E+01	-3.815E-01	2.289E-03	-4.344E-06
Sorghum	-1.741E+00	-3.314E-03	2.286E-04	-7.190E-07
Soybean	1.314E+01	-2.420E-01	1.437E-03	-2.665E-06

[1] $K_c = C_1 + C_2X + C_3X + C_4X$ (X = Date in Julian Calendar).

E+00 = 1; E+01=10^1; E-01=10^{-1}.

The computer model consists of a user-friendly program with instructions displayed in a question-answer mode on the monitor screen to facilitate data entry. If the first run option is selected, the data describing the soil, crop, and field are requested. In this option when all necessary data are entered, the model will summarize them, using a few data-base subroutines, in three different data files. The user can name these files, but is required to remember them when the model asks for the name of each file during this and subsequent computer runs. The first two files will remain unchanged for the irrigation season and the third one will be automatically updated by the model at each time it is run. If the first run option is not selected, the model bypasses all of the data entries and instead asks for the name of those files in which the data were previously stored. Finally, the last data entry phase will be for climatic data. The user will have the option of entering them while running the model, using the monitor in the question-answer mode, or having them ready according to the required format. In the latter case the model will ask for the name of the file.

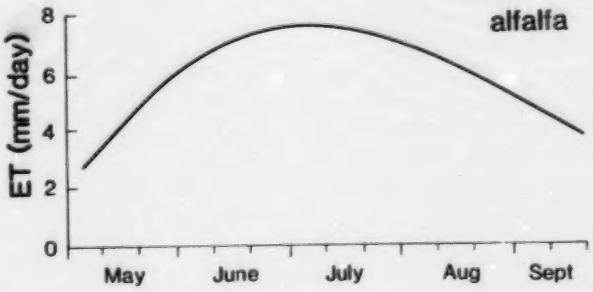


Fig. 1. Average evapotranspiration of alfalfa for southern Alberta.

Fig. 2. Mean potential evapotranspiration based on relationship between evaporation and concurrent crop evapotranspiration.

With this background data the model is capable of determining all of the information required to manage irrigation more effectively. It calls up information from the data files created in advance and proceeds through a series of complex and tedious computations to determine: 1) how much available water remains in the soil reservoir since the last irrigation; 2) how fast the crop is withdrawing this remaining available water; 3) how soon the accumulated depletion will reach the allowable depletion (DPA), and finally, 4) when the field should be irrigated and how much water should be applied. The model repeats the process for forecasting irrigation for every field involved and summarizes the results in an output file. The output file illustrates the historic and updated moisture status, and the irrigation forecast for each of the fields involved in the program. It assists the irrigator in planning and managing the irrigation system more efficiently.

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